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PHASE I REPORT

CONTRACT NAS 9-5880

"DEVELOPMENT OF INSTRUMENTATION FOR MEASUREMENT OF BONE DENSITY"

January 10, 1967

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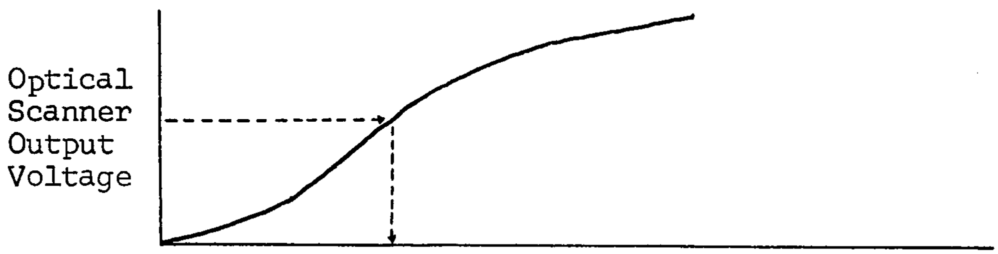
I. DESCRIPTION OF SYSTEM

A. System Operation

The purpose of the bone density measuring system is to evaluate the integrated bone density over a specific cross-section of bone. The problem may be described as follows.

A roentgenogram of a standard aluminum calibration wedge and the desired bone is obtained in a single exposure. This insures uniform exposure and processing conditions for the reference and the variable to be measured. The developed film is then scanned to measure optical density by means of a scanning microdensitometer. First, the image of the wedge is scanned to determine the relation between optical density and the thickness of the reference wedge as recorded on this particular film. The graphical representation of the optical scanner output for a scan of the wedge image may look similar to the curve shown in Figure 1.



Time (Distance along wedge or wedge thickness)

FIGURE 1. Typical Wedge Scan Curve

Secondly, the bone image is scanned along the desired cross-section. A typical curve is depicted in Figure 2.

Time (Distance along bone)

FIGURE 2. Typical Bone Scan Curve

The curves shown in Figures 1 and 2 represent the basic inputs for measurement of bone density. The computation system must then convert the optical scanner voltage output for the bone scan to a curve of equivalent density (in terms of wedge thickness) and integrate the area under the resulting curve. The conversion between optical scanner output for the bone scan and equivalent wedge thickness is made using the first curve. The curve is entered at the value of optical scanner output and the wedge thickness is read on the abscissa. This equivalent wedge thickness is used in the subsequent integration of the density.

In the analog system in use at Texas Woman's University, the conversion between optical scanner output during the bone scan and equivalent wedge thickness is made by using a nonlinear resistance slidewire output from a chart recorder. The nonlinearity can be manually adjusted with twenty potentiometers so that the output is approximately linear during a wedge scan. The integration is accomplished by using an electro-mechanical integrator. A block diagram of this system is shown in Figure 3.

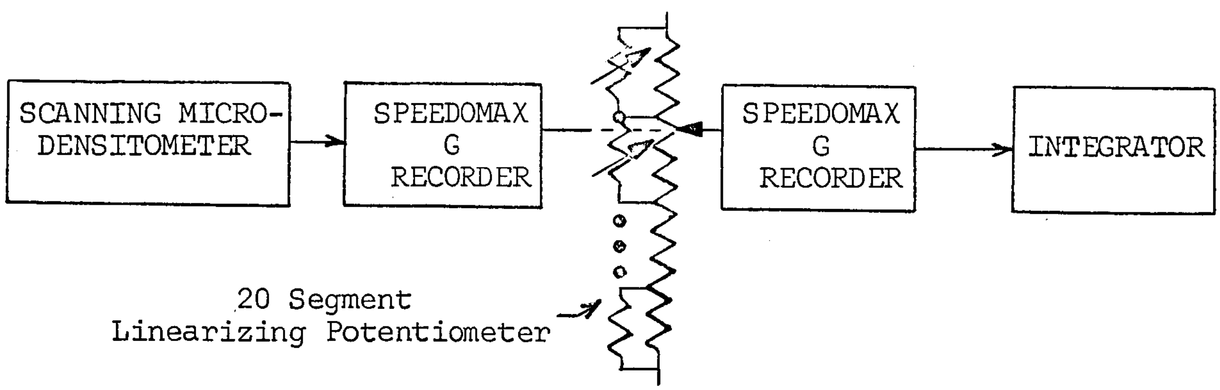


FIGURE 3. Block Diagram of Analog Bone Density Computer System

B. Description of Digital System

A system utilizing a digital computer has been implemented to perform the computation functions similar to those performed by the analog system. The optical scanner output voltage is converted to a digital format for storage and subsequent processing by the digital computer. After both the wedge and bone scans have been completed, the computer converts the stored bone scan data to equivalent wedge thickness by using the stored wedge scan data. The bone density is then integrated along the scan by using the trapezoidal approximation integration formula. The block diagram of the digital instrumentation is shown in Figure 4.

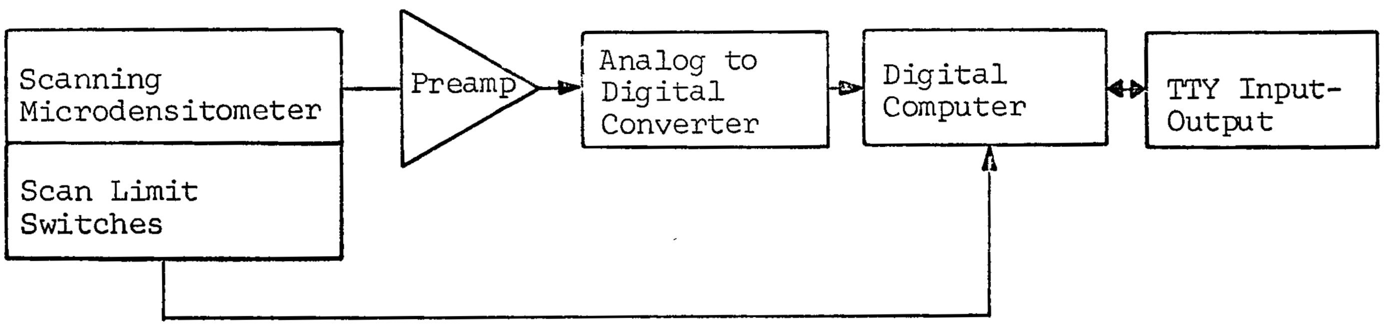


FIGURE 4. Block Diagram of Digital System

In operation, the data collection by the computer is controlled by the limit switches of the densitometer which mark the beginning and end of the scans. The sampling times are controlled by a clock in the computer. The teletype unit is used to control the computer by directing it to prepare for a wedge or bone scan, specifying bone scan speed used, specifying printout options desired, and in typing identifying information on the printout.

C. System Specifications (Digital Instrumentation)

The digital system prints out the integrated bone density in both the arbitrarily scaled system in which the area under the wedge scan curve is defined to be 6500 and also in the units of equivalent cross-section area of aluminum (square centimeters). The system will optionally print out subtotal areas of ten approximately equal length segments. (The lengths will be equal if the total number of samples is divisible by ten. If the total number is not divisible by ten, the initial increments will be increased by one sample each until the odd number of samples is utilized.) In addition to the integrated density and bone length data printed out, the printout includes a format for adding identifying information to the output page for a permanent record.

The system has the capacity to store 170 samples of the wedge scan data and 300 samples of bone scan data. The sampling rate established in the program is 1 sample per second. The standard wedge normally produces approximately 156 samples over 13 centimeters at a 5.0 cm/sec scan rate. The capacity of 300 samples of bone scan data allows scanning a bone length of 25 centimeters at 5.0 cm/sec scan speed. In use, the bone scan speed should be chosen so that the number of samples is as large as possible, up to a maximum of 300. Note: If the storage limitations of the system are exceeded, the printout data will not be valid.

The system is set up to operate with an analog voltage input in the range of 0 to -10 volts where 0 volts represents maximum optical density.

The accuracy is primarily dependent on operator care in setting up the images for scanning. (A more detailed discussion is contained in Section III of this report.)

II. OPERATING INSTRUCTIONS FOR THE DIGITAL SYSTEM

This section assumes that the program is in the computer and ready for operation. A later section will specify the means of loading and/or checking the program routine in the computer.

The program is operated as follows:

1) Turn the POWER key on the computer. This provides power to the computer and its peripheral equipment. (Power to the densitometer, Speedomax G recorders, etc., is controlled in the usual manner.)

2) The program is started as follows: Set OCTAL 0201 in the SWITCH REGISTER. Set all Instruction Switches up except DEP (this switch is spring-loaded down), SING STEP and SING INST. Depress LOAD ADD, and then depress START. The teletype machine should print WAITING. (If WAITING is not printed out, the program in the machine should be checked as described in Section III C.) The switch positions described above are visually depicted in the accompanying diagram. No further computer switch manipulations are required.

3) Any time WAITING is typed out, the program is waiting for two control numbers to be typed into the computer. These two numbers, designated KS and IPS in the program are single digit numbers and are entered in sequence. They should be entered without a decimal point and separated by a comma. These numbers direct the program to prepare for either a wedge or bone scan and specify the printout desired. When it first starts and prints out WAITING, the program is waiting for control numbers to direct it to scan the wedge and to specify if the heading printout is desired. The control numbers should be typed in as either 9,0 or 9,9. If 9,0 is entered, the heading and information printout is skipped. If 9,9 is entered, the heading printout is made. During this printout, the program stops after each colon and waits for the operator to type in the identifying information. The program will resume after a line-feed is typed.

4) When the program is ready for the wedge, the computer will type WEDGE. Prepare the optical scanner to scan the wedge (dark end first). When ready to scan, depress the tab bar. Note: the wedge scan speed should be 5.0cm/min. The scan limits to the computer are controlled by the scan drive switch and the stop limit switches. Scans should be started at one desired limit and terminated by the limit switch at the other limit.

5) Switch the scanner drive on. The switch and the limit on the scanner start and stop data collection by the computer.

6) When the wedge scan is completed, the computer will type WAITING. The control numbers should then be entered as either -9,0 or 0,-9. These control numbers direct the computer to prepare for a bone scan and specify the form of the data printout. If -9,0 is entered, the computer will type out only the total area under the density curve. If 0,-9 is entered, the computer will type out the area under each of ten approximately equal segments and the total area.

7) After the above entry, the computer types SCAN SPEED. The scan speed of the bone scan must be typed in. The scan speed should be typed in with a decimal point such as in 5.0 or 2.5 centimeters per minute.

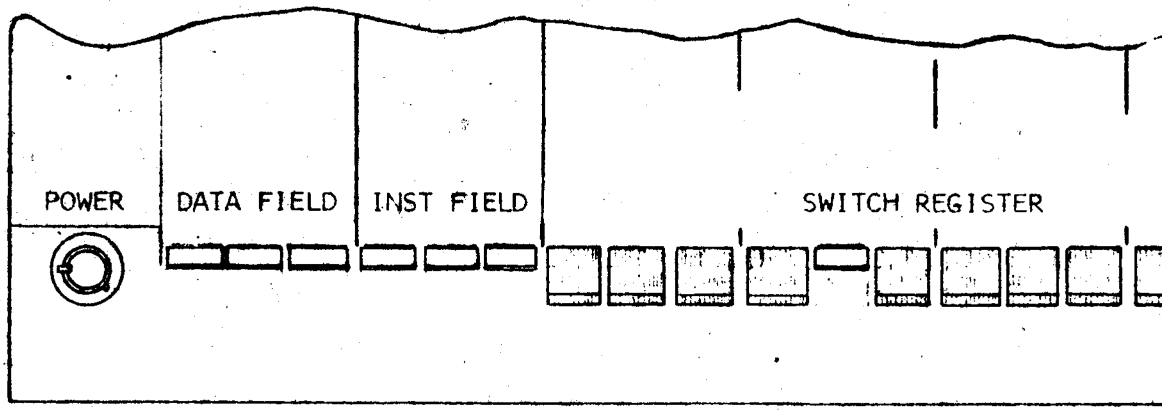
8) The program then allows one line of identification to be typed. A carriage return causes the program to proceed.

9) The program then prepares to accept the bone scan data and the computer types BONE. Prepare the x-ray image for the scan. When ready to scan, depress the tab bar.

10) Switch the scanner drive on. The drive switch and limit switch on the scanner start and stop data collection by the computer. The computer proceeds to use the bone scan data to find wedge equivalents, integrates the values, and prints out the results.

11) The program then returns to the WAITING status ready to receive a new set of control numbers. At this point several alternatives

are available. If the next bone scan will require the use of a different reference wedge image, return to Step 3 of this procedure. If the next bone scan will require only a change in bone scan speed, return to Step 6 of this procedure. If the next bone scan requires no change in the reference wedge or scan speed, the control numbers may be entered as 0,0 or 0,9. These two entries cause the computer to use the same scan speed entered previously. The 0,9 entry causes the computer to type out the area under each of ten approximately equal segments of the density curve and the total area. The 0,0 entry causes printout of only the total area.



PDP-8 COMPUTER SWITCH PC

OPERATING INSTRUCTIONS:

1. Turn Power Key on.

2. Set switches as shown above.
   Depress LOAD ADD, release.
   Depress START, release.

3. After WAITING is typed out, enter one of the following on the teletype:

   9,0 If heading printout is not desired

   9;9 If heading printout is desired

   If heading is printed, type in identifying information each time printout stops; proceed to next heading printout by depressing the line-feed key. After the heading is finished computer will printout WEDGE.

   If heading is skipped, computer will printout WEDGE.

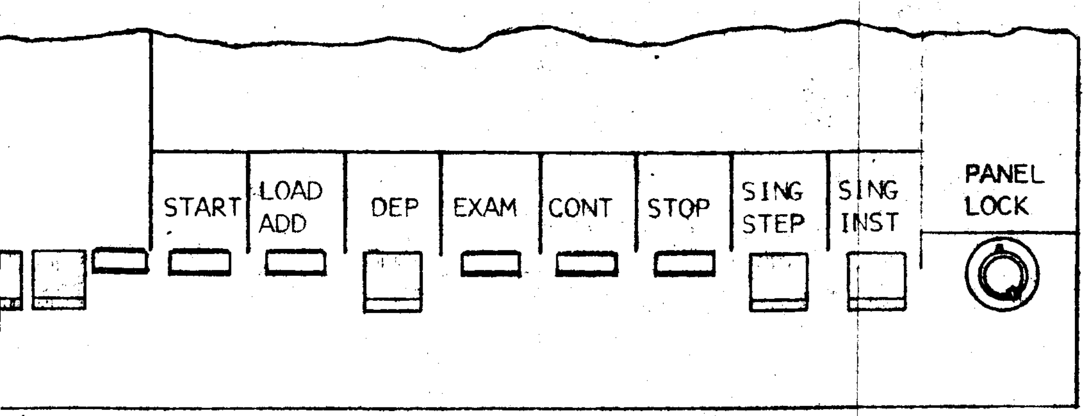
4. Prepare optical scanner for wedge scan, and set stop limit switch. Just prior to beginning wedge scan with switch on densitometer, depress tab bar on the teletype.

5. Switch scan drive on.

6. After the scan is completed, the computer will printout WAITING. Enter one of the following on the teletype:

   -9, 0 If only total area under the bone density curve is desired.

   0, -9 If total area and area's of ten segments are desired.



SITIONS FOR BONE DENSITY PROGRAM

7. The computer will printout SCAN SPEED. Enter the bone scan speed on the teletype with a decimal point as in 5.0 or 2.5 centimeters per minute.

8. The program allows space for the operator to type in one line of information at this point. A CARRIAGE RETURN causes the program to proceed.

9. Prepare film for bone scan and set stop limit switch. Just prior to beginning bone scan with switch on densitometer, depress tab bar on teletype.

10. Switch scan drive on.

11. At end of scan, computer will print data and will then print WAITING.

Proceed as follows:

a. To scan a new wedge - bone combination, return to step 3 in this procedure.

b. To use last wedge scan information, but a different bone scan speed, return to step 6 in this procedure.

c. To use last wedge scan information and same scan speed, type on the teletype:

0,0 If only total area is to be printed.

0,9 If total and 10-segment areas are to be printed.

III. DIGITAL COMPUTER PROGRAM

A. Method and Accuracy of Computation Procedure

Description of Transfer Function Procedure

The digital computer samples the output of the optical scanner at equal increments during the scan of the reference wedge and the bone. The data collected is stored in the computer memory for subsequent processing.

The wedge image is scanned first. Optical scanner output is sampled at equal time intervals and the values are sequentially stored in computer memory. The uniform speed scan is started at the thin end of the wedge and the thickness of the wedge is a linear function of distance, thus the time scale and storage location indexes are linearly related to wedge thickness. The scanner output sample stored in each location is a measure of the optical density at a point and the index of the location is a measure of the wedge thickness corresponding to that optical density. This data stored during the wedge scan is the transfer function relating optical density to wedge thickness.

The bone image is scanned in the same manner with the samples of the optical scanner output being stored sequentially in the computer memory. These samples are also taken at equal time intervals with a constant scan speed causing them to be uniformly spaced along the bone image.

After the bone has been scanned, the computer converts each sample of the optical scanner output to an equivalent wedge thickness using the stored transfer function. This conversion is made by comparing the scanner output sample from the bone to successive output samples from the wedge until a wedge sample larger than the bone sample is found. The equivalent wedge thickness is then computed by using linear interpolation between the index of the larger wedge sample and the index of the immediately preceeding smaller sample.

The integrated density of the bone is computed by using the equivalent wedge thickness at each sample point and applying the trapezoidal approximation integration formula. The output is normalized such that if the standard wedge were to be rescanned (instead of using a bone), the area under the density curve would closely approximate 6500.

<u>Accuracy limitations</u>

The accuracy limitations introduced by the use of the digital computer are listed below:

(a) Quantization in the analog to digital conversion at the input. (The resolution and stability of the analog to digital converter is at least an order of magnitude better than the accuracy of the analog input, so this effect is negligible.)

(b) Sampling the wedge and bone image scans at intervals causes a slight reduction in accuracy. The wedge is typically represented with 156 uniformly spaced samples, while the number of samples from the bone image is determined by the bone length and scan speed. The computer program can accept 300 bone image samples taken at one second intervals. (Thus the scan speed should be selected to obtain as many points as possible, up to a maximum of 300.)

(c) The most serious accuracy limitation appears to be "noise" on the optical scanner output during the wedge scan. This noise is most prominent where the image is very light and the optical density is determined by the presence of relatively few silver particles appearing in the scanner beam path. This noise could be smoothed effectively by using a larger scanning aperture, but this is not feasible with the present microdensitometer as the calibration depends on using the same aperture for both the wedge and bone scan.

B. Program Details

The computer used for this application was a basic Digital Equipment Corporation PDP-8 with a memory of 4096 twelve bit words and with only a basic adding arithmetic unit (A register only). The capacity of the computer and the problem are closely matched to each other. To be able to achieve the maximum flexibility in modification of the program and to be able to perform the calculations required, the PDP-8 FORTRAN system was chosen. The FORTRAN system furnished the flexibility of modification, the necessary arithmetic packages, and flexible input and output options. The space requirements for supplementary subprograms, the basic FORTRAN control program, and heading information exceeded the memory of the computer. In order to overcome this problem, the subprograms were overlayed over unused portions of the FORTRAN operating system and the heading information was combined with control information and condensed to a character string that is scanned by the control program INPRN. Finally hand coded instructions were inserted to utilize the last remaining spaces in the memory. There were three known unused locations in the computer upon completion of the program.

The main program is written in FORTRAN and is primarily the arithmetic portion of the program. One may note that there are some odd PAUSE statements in the program. These PAUSE statements with numbers following them are departures from the main program to a subroutine. The FORTRAN system generates an address carrying jump to the octal equivalent location given by the decimal number following PAUSE.

The normalization and integration in the main program is based on the assumption that the thickness of the wedge is a linear function of length and that the total area under the normalized wedge curve is 6500. The wedge scan appears nonlinear because of the process of roentgenographic exposure and processing.

The total area under the normalized wedge curve is assumed to be

$$\text{Area} = \tfrac{1}{2} * \text{ANW} * h = 6500$$

where ANW is the length of the wedge and h is the maximum thickness. The thickness (B) of the wedge at any point (K) is given by

$$B = \frac{K * h}{\text{ANW}} .$$

Combining the two equations yields

$$B = \frac{13000 * K}{\text{ANW} * \text{ANW}} .$$

The factor $\frac{13000}{\text{ANW} * \text{ANW}}$ is defined as CFAC in the program.

To find the wedge equivalent at a point along the bone scan, the program starts with K = 2 and indexes K until it finds the first value of optical scanner output from the wedge scan that exceeds the value of the optical scanner output from the point on the bone scan. Linear interpolation between the point K and the point K-1 is then used to determine the equivalent value of K to use in the integration.

The bone scan is broken into ten approximately equal segments for the integration. The integration formula used is

$$A = \text{CFAC} * \sum_{J=IS}^{J=IE} K(J) * \text{AMV}$$

where AMV = ½ at the end points of each interval and AMV = 1 at all internal points.

The FORTRAN language program listing and flow chart are shown in Figures 5 and 6. Discussions of individual subroutines, program listings and flow charts follow.

FIGURE 5.

MAIN PROGRAM LISTING

BONE DENSITY CALCULATIONS

```
    C; BONE DENSITY CALCULATIONS
     ; DIMENSION IW(100),IB(300),ICHAR(115)
   10; IW(1)=0
     ; IB(1)=0
     ; NP=10
     ; NW=10
     ; GO TO 8
    1; KS=1
     ; PAUSE 2176
     ; ANW=NW
     ; GO TO 8
    2; KS=0
     ; TYPE 1000
 1000; FORMAT(/,"SCAN SPEED")
     ; ACCEPT 2004, SPED
 2004; FORMAT(F)
     ; CFAC=(13000.0)/(ANW*ANW)
    3; PAUSE 2304
     ; PAUSE 2176
     ; ANP=NP
     ; WL=ANP*SPED/60.0
     ; TYPE 1018,NP,WL
 1018; FORMAT("NUMBER OF SAMPLE POINTS: ",I,/,"BONE LENGTH (CM): ",E,/)
     ; IF(IPS)4,5,4
    4; TYPE 1019
 1019; FORMAT(/,"       SEGMENT       INTEGRATED COUNTS",/)
    5; IQ=NP/10
     ; IR=NP-(10*IQ)
     ; IS=1
     ; IE=IQ
     ; AS=0.0
     ; A=0.0
     ; AMV=0.5
     ; DO 60 I=1,10
     ; IF(IR)62,62,61
   61; IE=IE+1
     ; IR=IR-1
   62; DO 67 J=IS,IE
     ; IBX= IB(J)
     ; DO 65 K=2,NW
     ; IF(IBX-IW(K))63,64,65
   63; KK=K-1
     ; X=KK
     ; IWK=IW(KK)
     ; DYN=IBX-IWK
     ; DYD=IW(K)-IWK
     ; R= X+ (DYN/DYD)
     ; GO TO 66
   64; R=X
     ; GO TO 66
   65; CONTINUE
     ; PAUSE
   66; Y=R*AMV
     ; A=A+Y
     ; AS=AS+Y
     ; AMV=1.0
```

FIGURE 5.

MAIN PROGRAM LISTING

BONE DENSITY CALCULATIONS

```
  67; CONTINUE
    ; IS=IE+1
    ; IE=IE+IQ
    ; Y2=Y/2.0
    ; A=(A-Y2)*CFAC
    ; IF(IPS)6,7,6
   6;TYPE 2000, I, A
2000; FORMAT(/,"       ",I,"          ",E)
   7; A=Y2
  60; CONTINUE
    ; AR=(AR-Y2)*CFAC
    ; A=AR*(0.00245/SPED)
    ;TYPE 2001,AR,A
2001; FORMAT(/,/,"       TOTAL:        ",E,"  ",E,/,/,/,/,/)
   8; TYPE 2002
2002; FORMAT("WAITING",/,/)
    ; ACCEPT 1002,KS,IPS
1002; FORMAT(I,I)
    ; IF(KS)2,98,1
  98; IF(IPS)2,3,3
    ; END
```

```
IW    7325
IB    6651
ICHA  6466
NP    6461
NW    6457
KS    6455
ANW   6451
SPED  6445
CFAC  6442
ANP   6434
WL    6431
IPS   6425
IQ    6424
IR    6422
IS    6420
IE    6416
AR    6413
A     6405
AMV   6377
I     6373
J     6366
IRX   6365
K     6364
KK    6362
X     6356
IWK   6355
DYN   6352
DYD   6347
B     6344
Y     6341
Y2    6322
  6321   6324
```

FIGURE 6.

MAIN PROGRAM FLOW CHART

BONE DENSITY CALCULATIONS

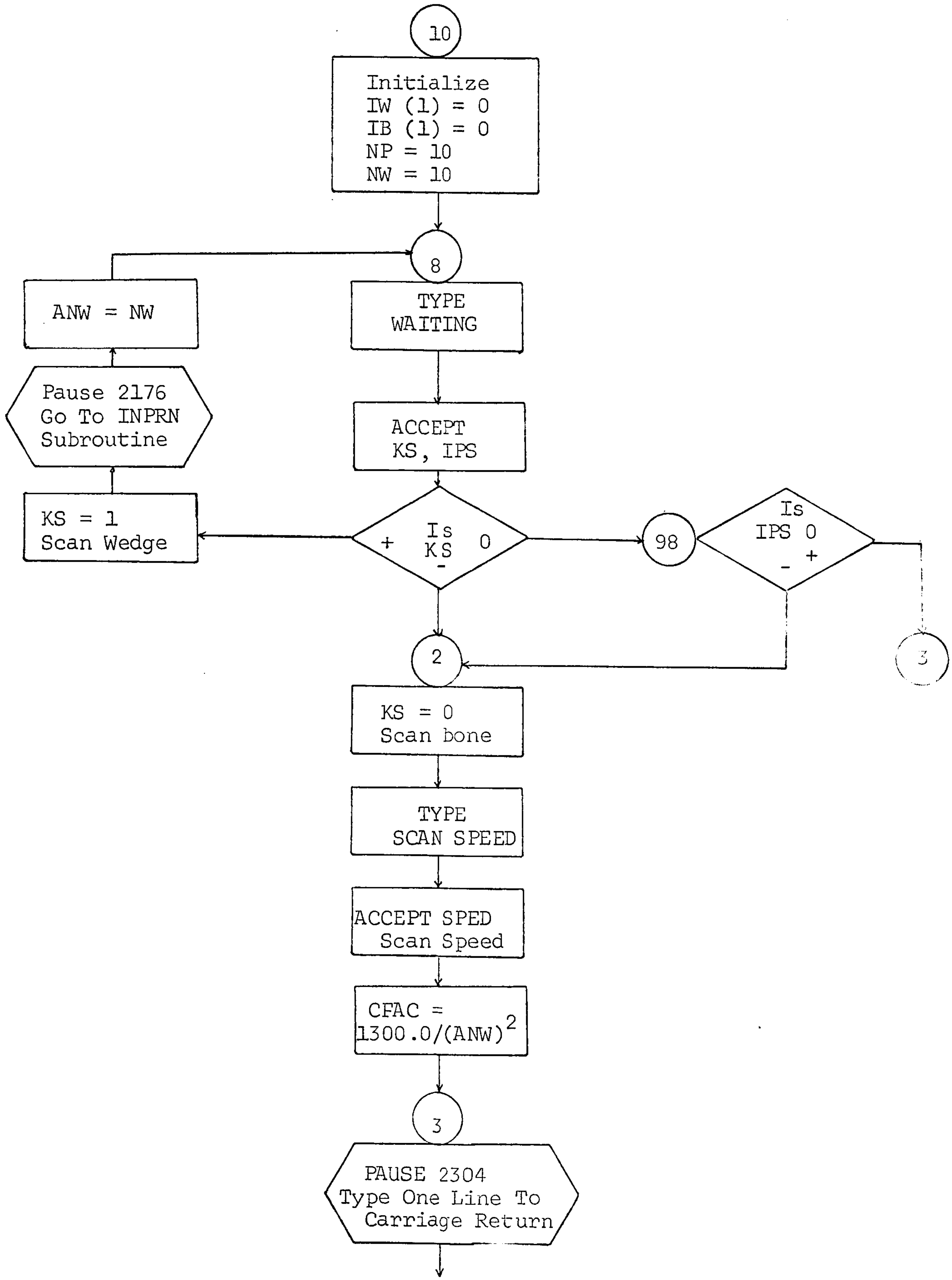


FIGURE 6.

MAIN PROGRAM FLOW CHART

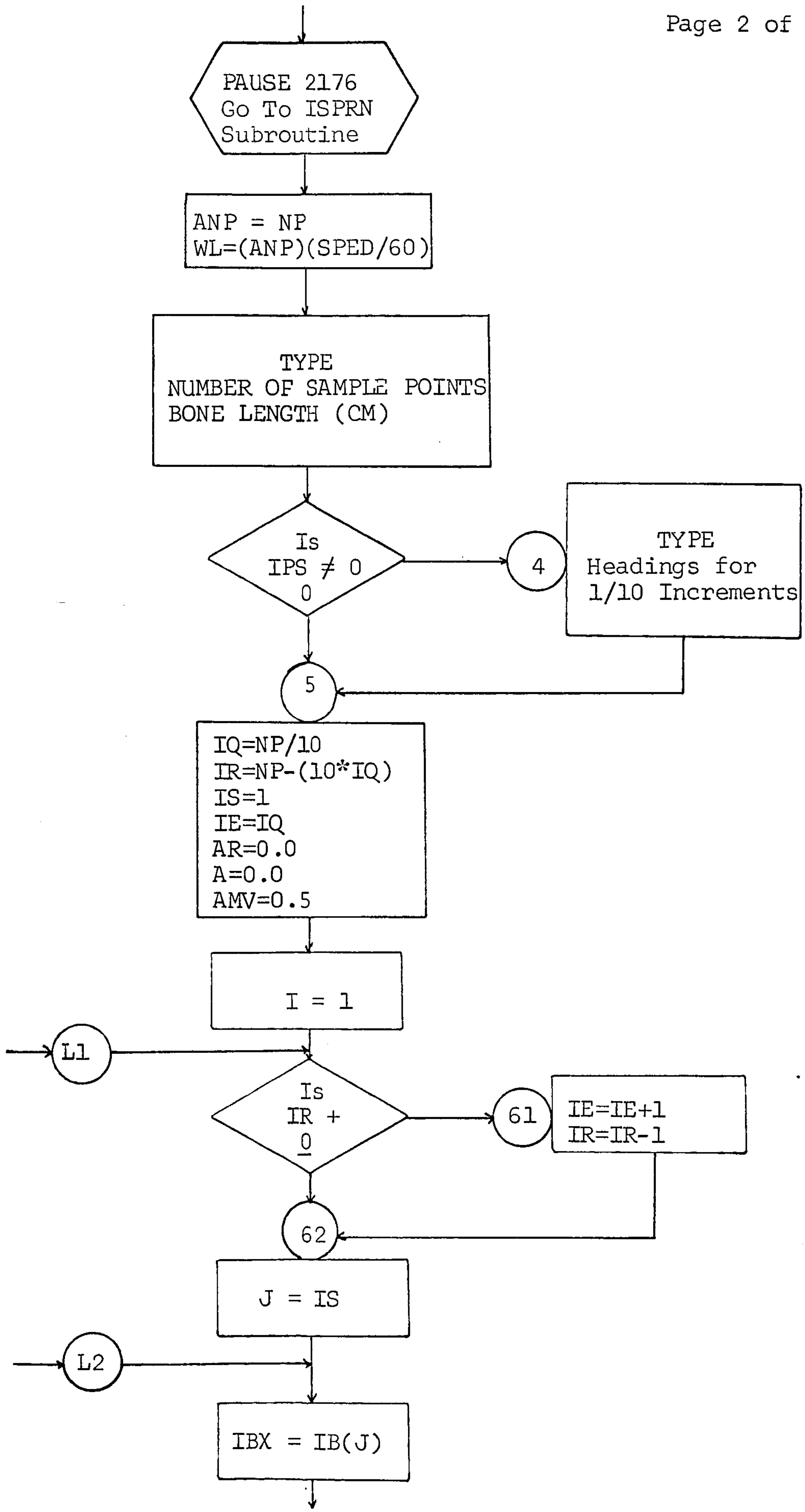


FIGURE 6.

MAIN PROGRAM FLOW CHART

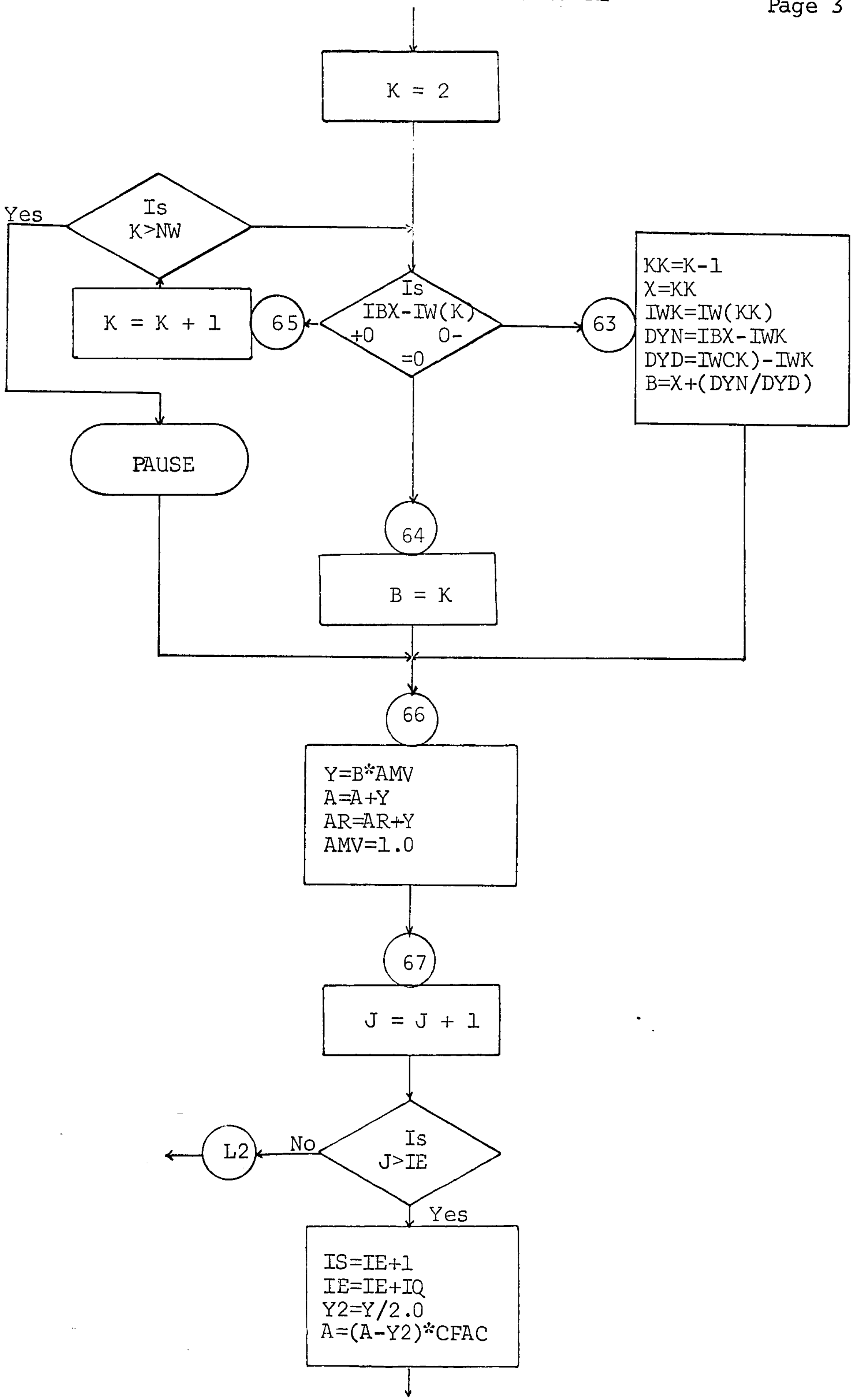
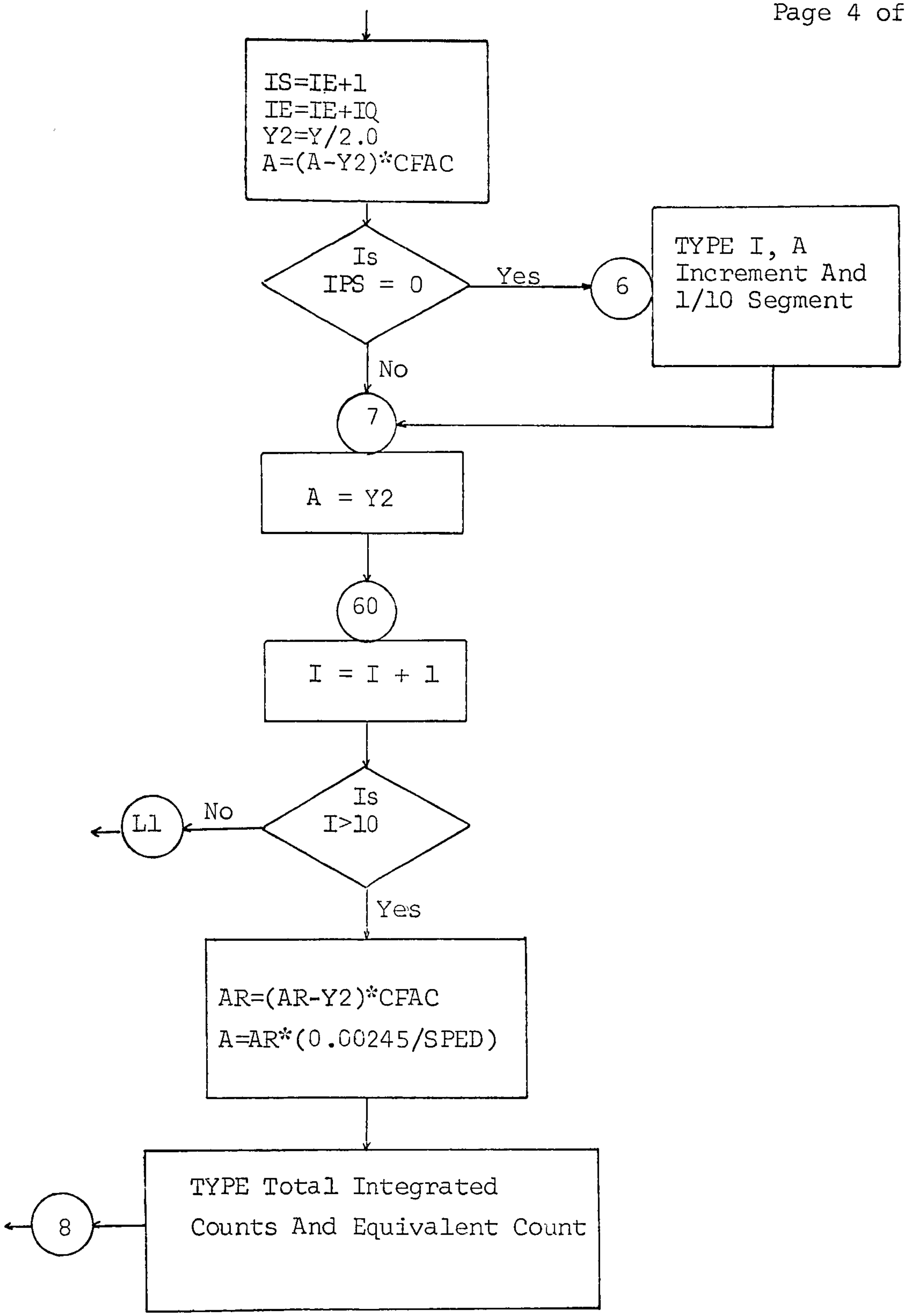


FIGURE 6.

MAIN PROGRAM FLOW CHART



INRPN - Internal Control Routine

This routine is the central program for the internal control of the analog to digital conversion routines and the wedge heading printing rouiine. The subroutine is essentially a decision and switching network. It tests KS and IPS to determine whether to set up for a bone or wedge scan and as to whether to print or not print headings in unscrambling the character series it detects from the character it acquires what function to perform. It detects whether or not a character is a normal alphabetic character (A - Z). If it is an alphabetic character, it prints the character. If the character is other than A-Z, it is interpreted and various other functions occur. The following are the characters recognized and the functions.

CHARACTER	PACKED CHARACTER from ASA-33 Code	FUNCTION
Space	40	Print space
!	41	Go wait for tab bar to be depressed, carriage return, then line feed
$	44	End the routine
*	52	Convert analog to digital
/	57	Line feed one line
:	72	Print colon and one space, wait for carriage return, then line feed
;	73	Set up for analog to digital conversion

Although the program is lengthy and the planning of the original logic was rather complex, the final working routine is straightforward.

The following instructions were hand coded into the final version of the program so as to allow special controls by KS and IPS to skip preliminary headings for a wedge scan or rescan.

ADDRESS	INSTRUCTION	
4211	5612	JMPI
4212	4571	ADDRESS
4571	7450	SNA
4572	5775	JMPI (BRSC)
4573	7300	CLACLL
4574		JMPI (Tie)
4575	4216	(BRSC)
4576	4371	(Tie)
4577		
4371	1776	TADI (LIPS)
4372	7440	SZA
4373	5213	JMP (4213)
4374	1377	TAD (WEDGS)
4375	5217	JMP (4217)
4376	6425	(LIPS)
4377	6633	(WEDGS)

INPRN subroutine listing and flow chart are shown in Figures 7 and 8.

FIGURE 7.

INPRN SUBROUTINE LISTING

```
                *4200
                / INITIAL PRINT ROUTINE
4200  0000  INPRN,  0             / ENTRY
4201  7300          CLA CLL       / CLEAR A L
4202  1363          TAD CRCR      /GET CARRIAGE RETURN CHAR.
4203  4737          JMS I PRIN    / GO PRINT
4204  1010          TAD 10        / GET 10
4205  3345          DCA S10       / SAVE LOC 10
4206  1360          TAD MSKU      / GET MASK CONSTANT
4207  3347          DCA MSK       / SET MSK
4210  1766          TAD I LKS     / GET KS
4211  7450                                    JMPI (4571)
4212  5216                                    (HAND CODED INSTRUCTIONS)
4213  7300          CLA CLL       / CLEAR A L
4214  1367          TAD LOSTR     / GET START OF CHARACTERS
4215  5217          JMP LX        / JUMP TO PROCEED
4216  1370  BRSC,   TAD BLIST     / GET START OF BONE LIST
4217  3010  LX,     DCA 10
4220  7300  L1,     CLA CLL       / CLEAR A L
4221  1347          TAD MSK       / GET MSK
4222  7500          SMA           / IS MSK 7700
4223  5240          JMP L077      / NO
4224  7300          CLA CLL       / YES CLEAR A L
4225  1410          TAD I 10      / GET NEXT CHARACTER
4226  3346          DCA SC        / SAVE CHARACTER
4227  1346          TAD SC        / SET IN A
4230  0347          AND MSK       / GET UPR
4231  7012          RTR           / SHIFT RIGHT 2     2
4232  7012          RTR           / SHIFT RIGHT 2     4
4233  7012          RTR           / SHIFT RIGHT 2     6
4234  3350          DCA PRC       / SAVE PRINT CHAR
4235  1361          TAD MSKL      / GET LOW MASK
4236  3347          DCA MSK       / SET MSK
4237  5246          JMP CKC       / GO CHECK
4240  7300  L077,   CLA CLL       / CLEAR A L
4241  1346          TAD SC        / GET SAVED CHAR
4242  0347          AND MSK       / MASK
4243  3350          DCA PRC       / SAVE AS PRINT CHAR
4244  1360          TAD MSKU      / GET UPR MASK
4245  3347          DCA MSK       / SET MSK
4246  7300  CKC,    CLA CLL       / CLEAR A L
4247  1350          TAD PRC       / GET CHARACTER
4250  1357          TAD M40       /SUBTRACT 40 TO CHECK 40
4251  7510          SPA           / IS CHARACTER NEGATIVE
4252  5300          JMP NORMC     / YES GO PROCESS NORMALLY
4253  7450          SNA           / IS SPACE
4254  5304          JMP SPCY       / YES GET SPACE
4255  1352          TAD M1        / SUBTRACT 1 TO CHECK 41
4256  7450          SNA           / IS CHARACTER EXCLAMATION MARK
4257  5314          JMP WFTB      / YES GO WAIT FOR SPACE
4260  1354          TAD M3        / SUBTRACT 3 TO CHECK 44
4261  7450          SNA           / IS CHARACTER CODE FOR END OF TAPE (DOLLA
4262  5334          JMP ENDT      / YES GO TERMINATE ROUTINE
4263  1355          TAD M6        / SUBTRACT 6 TO CHECK 52
4264  7450          SNA           / IS CHARACTER ASTERISK
4265  5332          JMP [illegible]  / YES GO CONVERT AD
```

FIGURE 7.

INPRN SUBROUTINE LISTING


```
4266  1353           TAD M5         / SUBTRACT 5 TO CHECK 57
4267  745Ø           SNA            / IS CODE FOR LINE FEED
427Ø  5317           JMP LFDY       / YES GO GET CODE FOR LINE FEED
4271  1356           TAD M13        / SUBTRACT 13 TO CHECK 72
4272  745Ø           SNA            / IS CODE FOR COLON
4273  53Ø6           JMP COCY       / YES GO SET COLON CHARACTER A(Ø)
42[illegible]  1352           TAD M1         / SUBTRACT 1 TO CHECK 73
42[illegible]  745Ø           SNA            / IS CODE FOR SEMI COLON
4276  5322           JMP SETAD      / YES GO SET A D CONVERTER A(Ø)
4277  74Ø2           HLT
43ØØ  73ØØ  NORMC,   CLA CLL        / CLEAR A L
43Ø1  135Ø           TAD PRC        / GET CHARACTER
43Ø2  1351           TAD TRE        / INSERT Ø3ØØ CODE
43Ø3  532Ø           JMP PRNTC      / GO TO PRINT
43Ø4  1362  SPCY,    TAD SPCR       /GET SPACE
43Ø5  532Ø           JMP PRNTC      / GO PRINT
43Ø6  1365  COCY,    TAD COLC       / GET COLON
43Ø7  4737           JMS I PRIN     / PRINT CHARACTER
431Ø  1362           TAD SPCR       / SPACE CHARACTER
4311  4737           JMS I PRIN     / PRINT CHARACTER
4312  474Ø           JMS I WATC     / WAIT FOR CAR. RET.
4313  5317           JMP LFDY       / GO LINE FEED
4314  4741  WFTB,    JMS I WATS     / WAIT FOR SPACE
4315  1363           TAD CRCR       / CARRIAGE RETURN
4316  4737           JMS I PRIN     / PRINT CHARACTER
4317  1364  LFDY,    TAD LFCR       / GET LINE FEED
432Ø  4737  PRNTC,   JMS I PRIN     /PRINT CHARACTER
4321  522Ø           JMP L1         / LOOPBACK
4322  1766  SETAD,   TAD I LKS      / GET VALUE OF KS
4323  745Ø           SNA            / IS ZERO
4324  533Ø           JMP SETBO      / YES ZERO SET BONE
4325  4742           JMS I ADWG     / NO SET FOR WEDGE  +1
4326  3766           DCA I LKS      / SET KS TO ZERO
4327  522Ø           JMP L1         / EXIT
433Ø  4743  SETBO,   JMS I ADBO     / SET BONE CONVERSION +Ø
4331  522Ø           JMP L1         / EXIT
4332  4744  CONAD,   JMS I ADCO     / GO TO AD CONVERT SUBROUTINE
4333  522Ø           JMP L1
4334  1345  ENDT,    TAD S1Ø
4335  3Ø1Ø           DCA 1Ø
4336  56ØØ           JMP I INPRN    / EXIT
4337  4434  PRIN,    PRINT
434Ø  44ØØ  WATC,    WAITCR
4341  44Ø7  WATS,    WAITSP
4342  4442  ADWG,    ADWEG
4343  446Ø  ADBO,    ADBON
4344  4476  ADCO,    ADCON
4345  ØØØØ  S1Ø,     Ø              / SAVE 1Ø
4346  ØØØØ  SC,      Ø              / CHARACTER SAVE
4347  ØØØØ  MSK,     Ø              / WORKING MASK
435Ø  ØØØØ  PRC,     Ø              / PRINT CHARACTER
4351  Ø3ØØ  TRE,     Ø3ØØ           / TELETYPE Ø3ØØ INSERT
4352  7777  M1,      -ØØØ1          / -1
4353  7773  M5,      -ØØØ5          / -5
4354  7775  M3,      -ØØØ3          / -3
4355  7772  M6,      -ØØØ6          / -6
4356  7765  M13,     -ØØ13          / -[illegible]
4357  774Ø  M4Ø,     -ØØ[illegible]         / -[illegible]
[illegible]  77ØØ  MSKU,    [illegible]             / [illegible] MASK
```

FIGURE 7.

INPRN SUBROUTINE LISTING


```
4361   0077   MSKL,   0077        / LOWER MASK
4362   0240   SPCR,   0240        / SPACE
4363   0215   CRCR,   0215        /CARRIAGE RETURN
4364   0212   LFCR,   0212        / LINE FEED
4365   0272   COLC,   0272        / COLON
4366   6447   LKS,    6447        / LOCATION OF KS
4367   6465   LOSTR,  6465        / LOC OF CHAR. STRING
4370   6640   BLIST,  6640        / LOCATION OF BONE START
```

```
ADBO     4343
ADBON    4460
ADCO     4344
ADCON    4476
ADWEG    4442
ADWG     4342
BLIST    4370
BRSC     4216
CAR      4406
CKC      4246
CLCONB   4475
CLCONW   4457
CLK      4516
CLOCK    4555
CLOK     4556
CNTR     4561
COCY     4306
COLC     4365
CONAD    4332
CONCOM   4542
CONLP    4512
CRCR     4363
C200     4456
C300     4474
ENCL     6374
ENDT     4334
IB       4566
ICNTR    4560
INPRN    4200
IW       4564
LFCR     4364
LFDY     4317
LKS      4366
LOSTR    4367
L077     4240
LX       4217
L1       4220
MSK      4347
MSKL     4361
MSKU     4360
M1       4352
M13      4356
M3       4354
M40      4357
M5       4353
M6       435[illegible]
```

FIGURE 7.

INRPN SUBROUTINE LISTING


```
NORMC   4300
NP      4567
NV      4563
NW'     4565
04      4554
PRC     4350
PRIN    4337
PRINT   4434
PRNTC   4320
RDKEY   4426
RPPT     44
```

FIGURE 8.

INPRN SUBROUTINE FLOW CHART

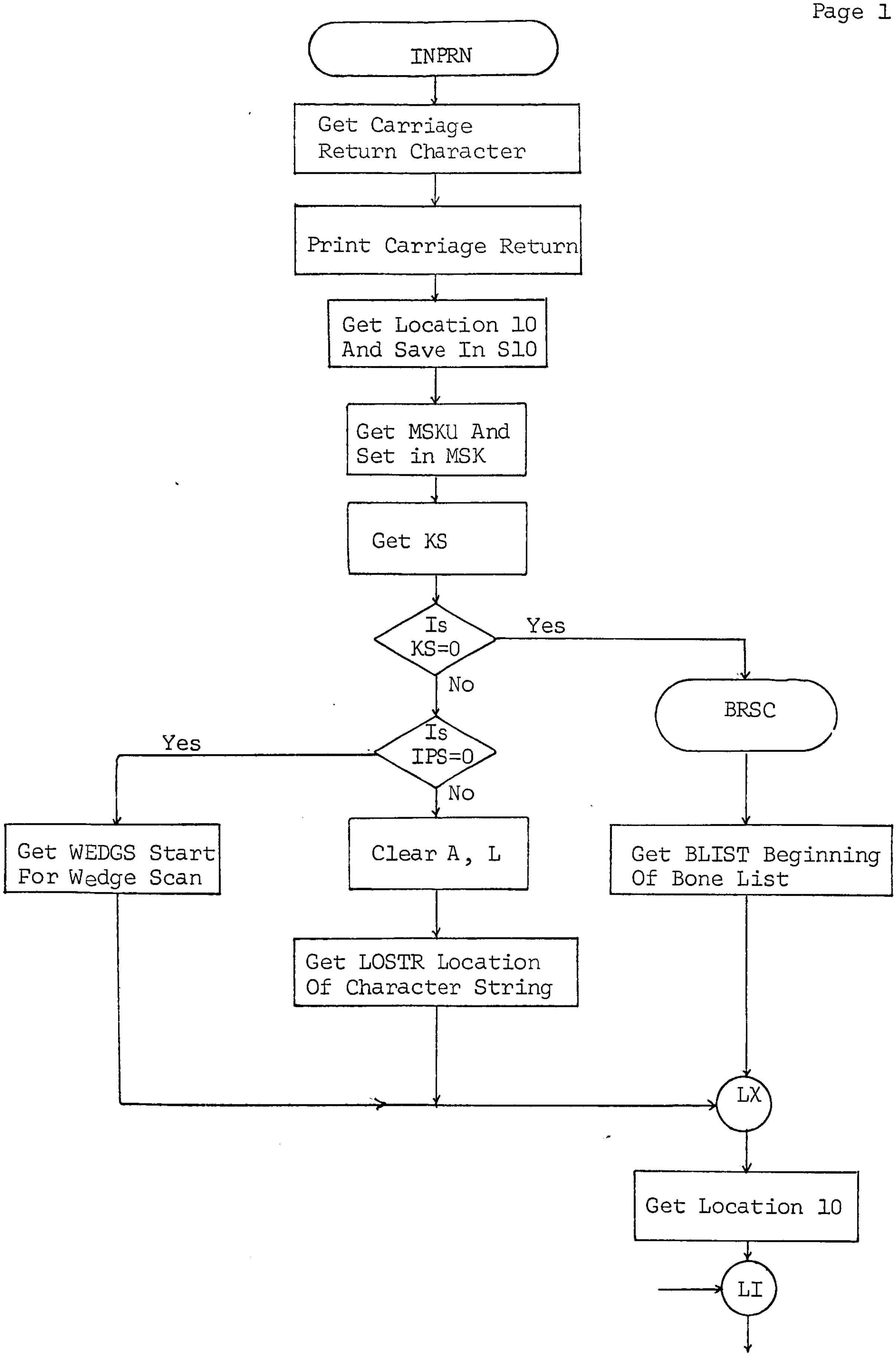


FIGURE 8. INPRN SUBROUTINE FLOW CHART

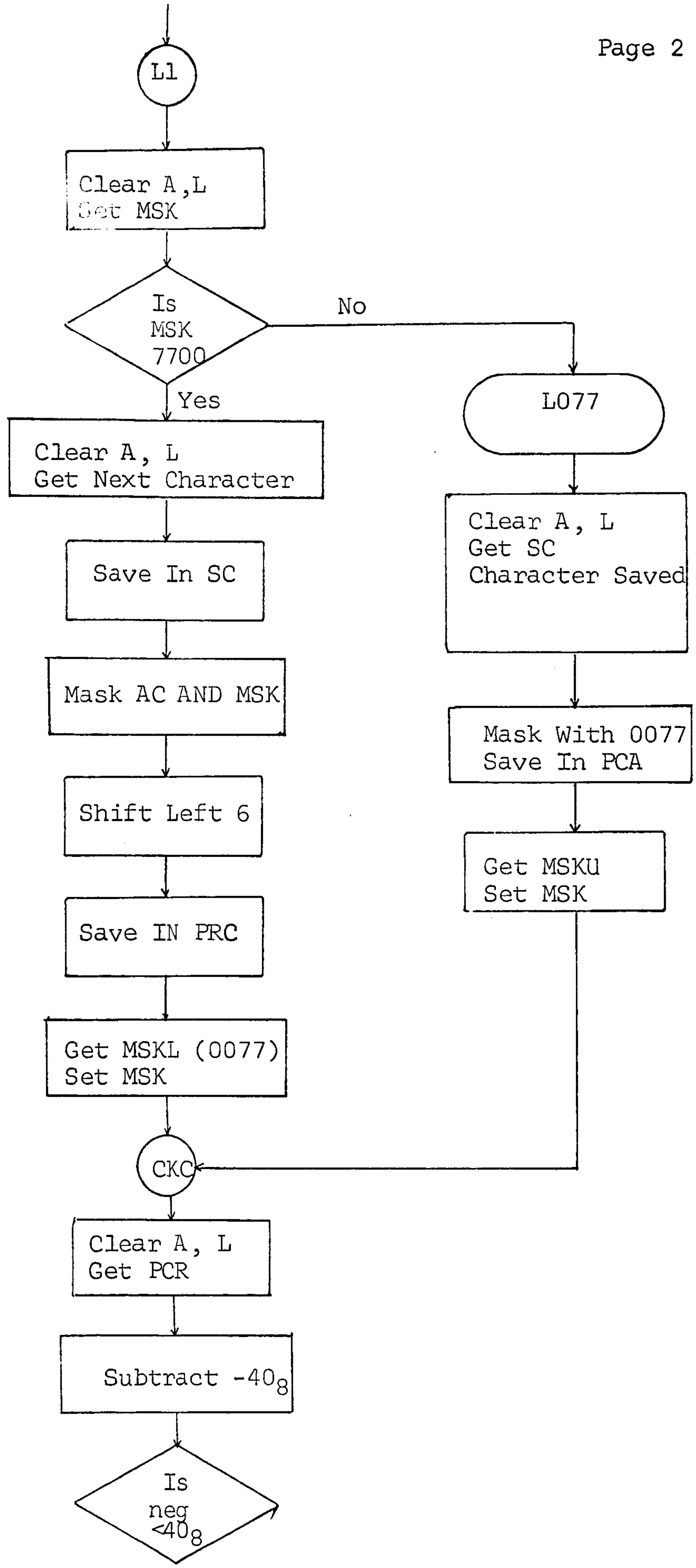


FIGURE 8. INPRN SUBROUTINE FLOW CHART

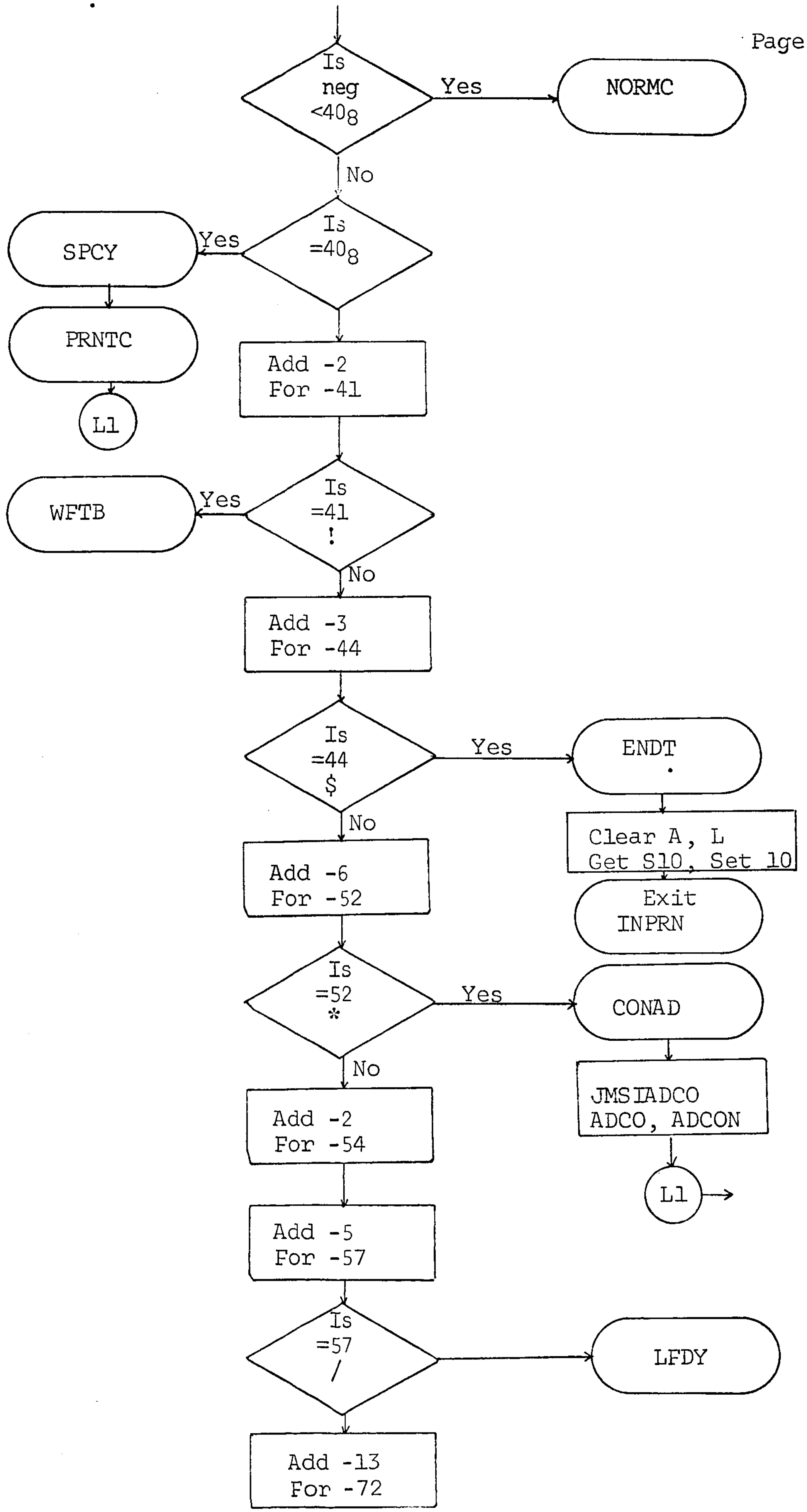


FIGURE 8.

INPRN SUBROUTINE FLOW CHART

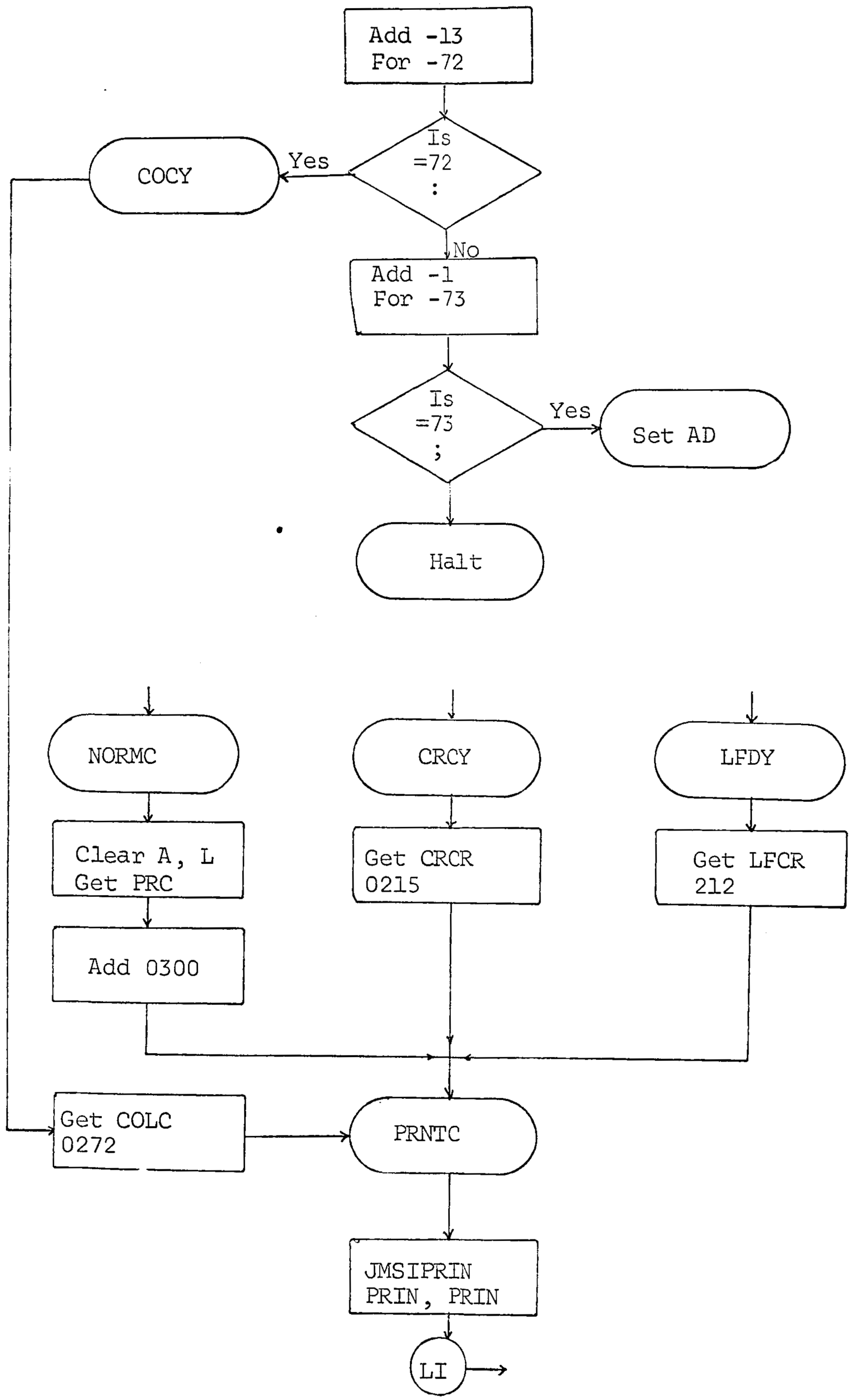
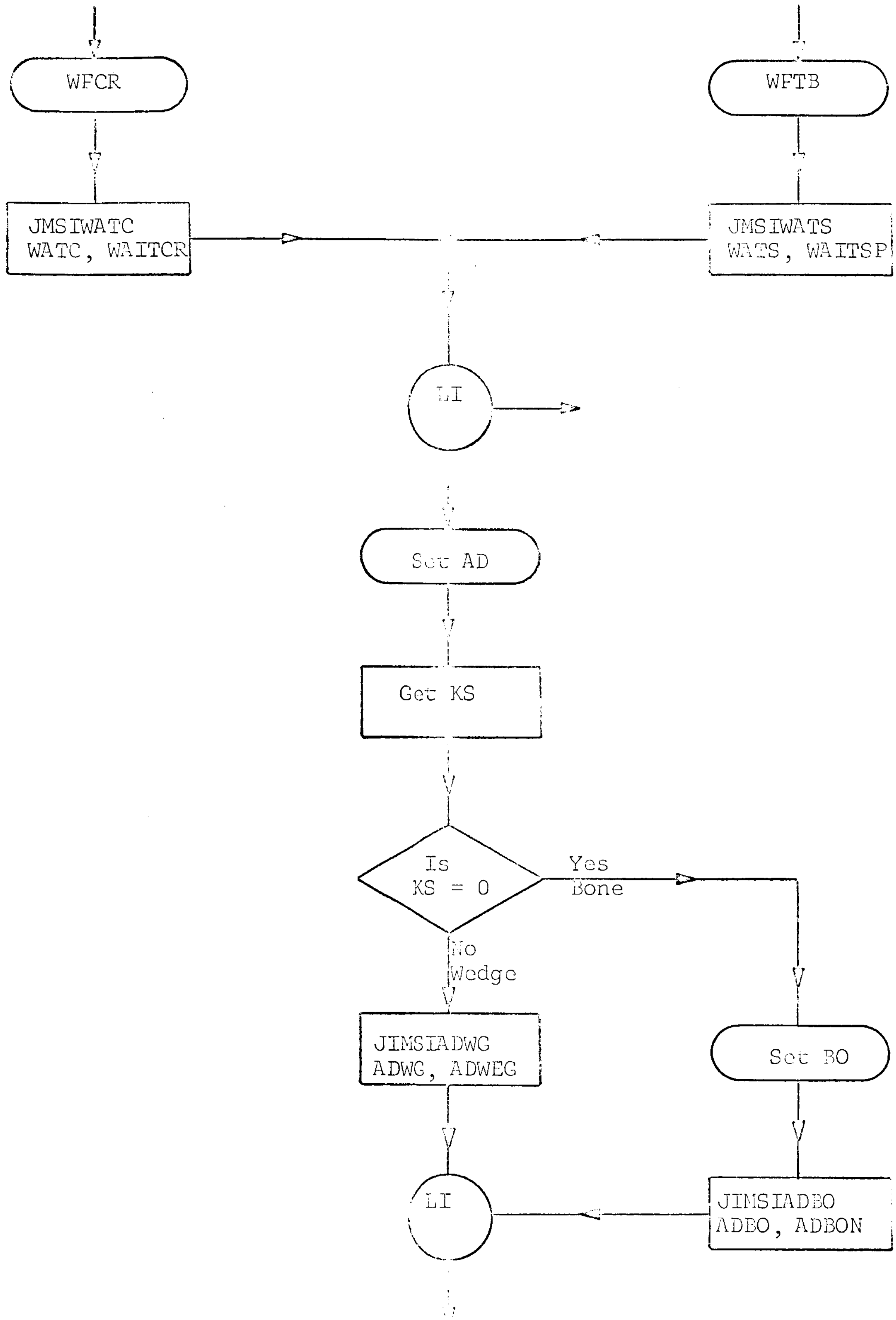


FIGURE 8.
INPRN SUBROUTINE FLOW CHART



WAITCR - Wait for Carriage Return

This subroutine reads a character that is typed on the keyboard then sends back the character to print on the carriage. The character is then tested to see if it is a carriage return character. If the character is a carriage return character, then an exit from the subroutine is performed otherwise the routine returns to repeat the above process.

WAITSP - Wait for Space Character

This subroutine is identical to the one above except that a space (tab) bar character is sought.

RPT - Repeat

This subroutine reads a character from the keyboard then prints the character on the carriage. (When the teletype is operating on line with the computer, striking a key does not cause the print bars to strike the carriage. The computer must send signals to cuase the latter to happen.)

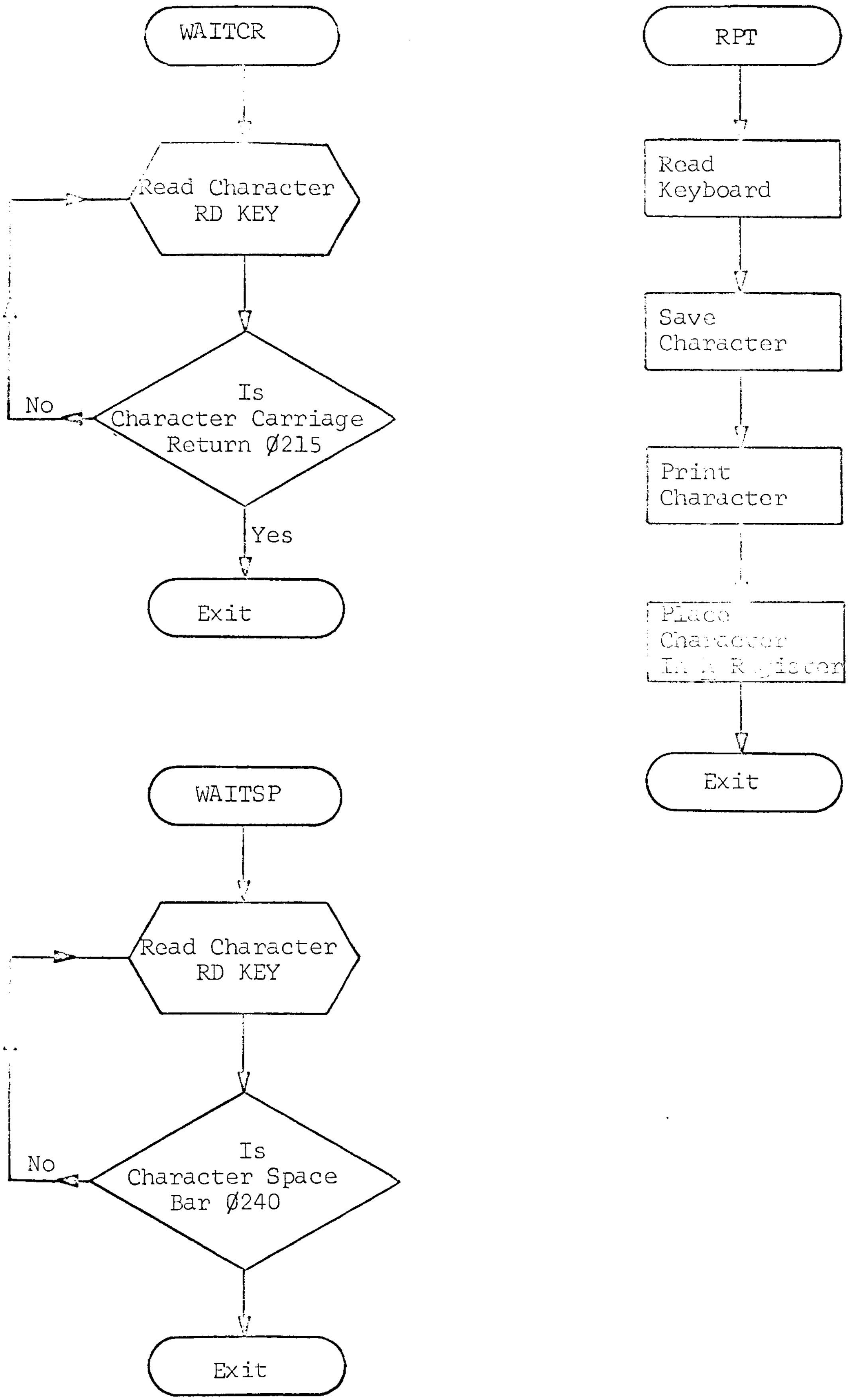
See Figures 9 and 10 for the listings and flow charts of WAITCR, WAITSP, and RPT.

FIGURE 9.

WAITCR, WAITSP, AND RPT LISTINGS

```
                *4400
                /WAIT FOR CARRIAGE RETURN
4400   0000    WAITCR,0               / ENTRY
4401   4216           JMS RPT         / READ CHARACTER AND PRINT BACK
4402   1206           TAD CAR         / ADD COMP OF CARRIAGE RETURN
4403   7440           SZA             / SKIP AC ZERO
4404   5201           JMP .-3         / WAIT FOR CARRIAGE RETURN
4405   5600           JMP I WAITCR    / EXIT
4406   7563    CAR,   -215
4407   0000    WAITSP,0               / ENTRY
4410   4226           JMS RDKEY       / READ KEYBOARD
4411   1215           TAD SPB         / ADD COMP OF SPACE BAR
4412   7440           SZA             / SKIP AC ZERO
4413   5210           JMP .-3         / WAIT FOR SPACE BAR
4414   5607           JMP I WAITSP    / EXIT
4415   7540    SPB,   -240
               / REPEAT READ CHARACTER AND PRINT BACK
4416   0000    RPT,   0000            / ENTRY TO REPEAT
4417   4226           JMS RDKEY       / READ KEYBOARD
4420   3225           DCA XXX         /  SAVE IN XXX
4421   1225           TAD XXX         /  RELOAD XXX
4422   4234           JMS PRINT       /  PRINT CHARACTER
4423   1225           TAD XXX         / RELOAD XXX
4424   5616           JMP I RPT       / EXIT
4425   0000    XXX,   0000            / SAVE LOCATION
```

FIGURE 10.
WAITCR, WAITSP, AND RPT FLOW CHARTS



RDKEY - Read Keyboard

This routine reads one character from the keyboards.

PRINT - Print

This routine takes a character and sends it from the computer to the teletype to cause the type bars to strike the carriage.

ADWEG - Set AD for Wedge

This routine sets up the analog to digital conversion routine for the wedge scan.

ADBON - Set AD for Bone

This routine sets up the analog to digital conversion routine for the bone scan.

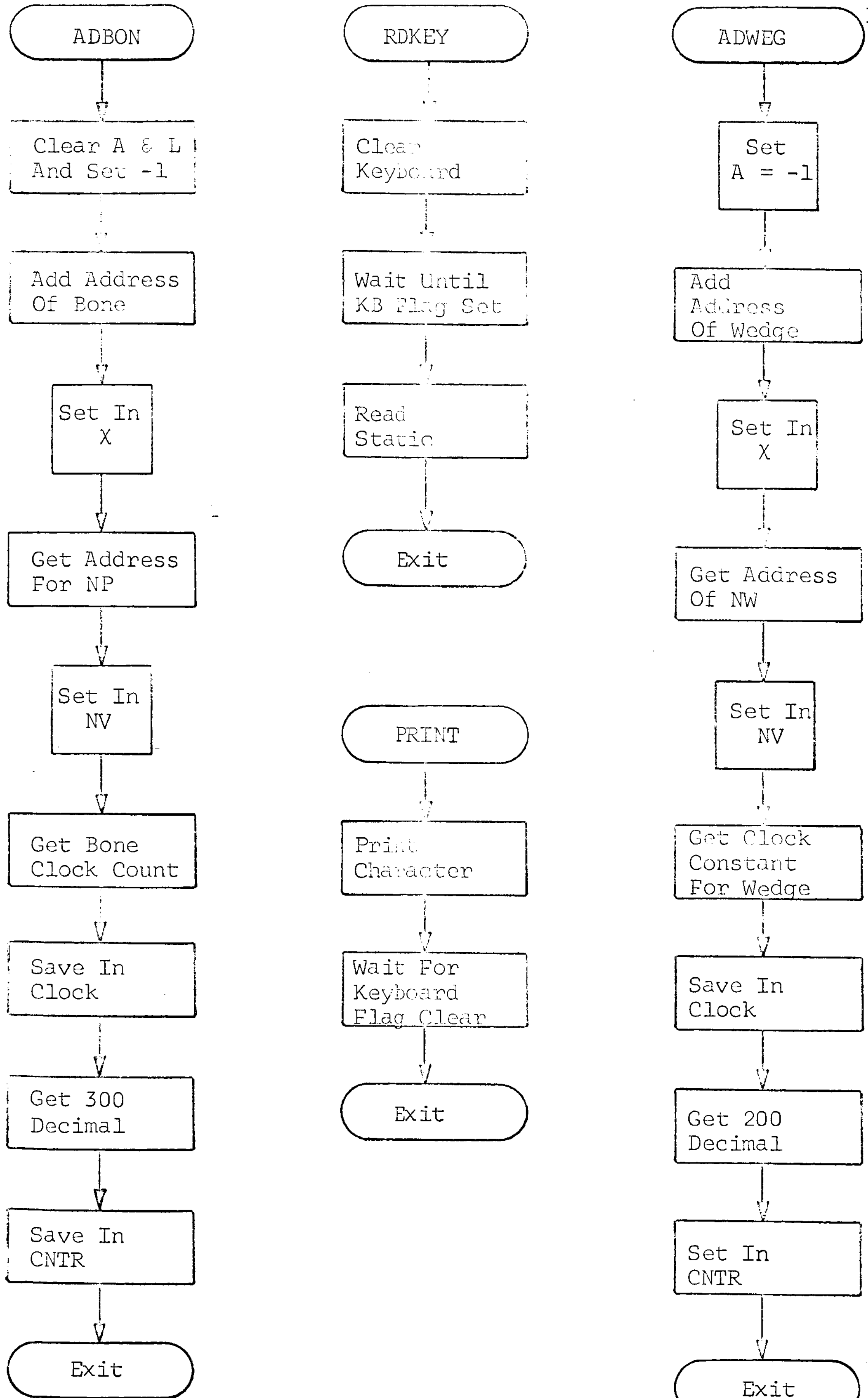
See Figures 11 and 12 for listings and flow charts of RDKEY, PRINT, ADWEG, and ADBON.

FIGURE 11.

RDKEY, PRINT, ADWEG, AND ADBON LISTINGS

```
                 / READ KEYBOARD
4426   0000   RDKEY, 0              / ENTRY
4427   6032          KCC            / CLEAR FLAG
4430   6031          KSF            / SKIP KB FLAG=1
4431   5230          JMP .-1        / RETURN TO WAIT
4432   6034          KRS            / READ KEYBOARD
4433   5626          JMP I RDKEY    / EXIT
              / PRINT A CHARACTER
4434   0000   PRINT, 0              / ENTRY
4435   6046          TLS            / PRINT CHARACTER
4436   6041          TSF            / SKIP FLAG SET
4437   5236          JMP .-1        / WAIT
4440   7300          CLA CLL        / CLEAR A L
4441   5634          JMP I PRINT    / EXIT
              / SET AD FOR WEDGE
4442   0000   ADWEG, 0              / ENTRY
4443   7201          CLA IAC        / CLEAR A AND SET TO 1
4444   7041          CIA            / COMPLEMENT TO MAKE NEG
4445   1364          TAD IW         / ADD ADDRESS
4446   3362          DCA X          / SAVE IN X
4447   1365          TAD NW         / GET ADDRESS OF NW
4450   3363          DCA NV         / SET IN NV
4451   1257          TAD CLCONW     / GET CLOCK CONSTANT
4452   3355          DCA CLOCK      / SET CLOCK
4453   1256          TAD C200       / GET WEDGE COUNTER DECIMAL 200
4454   3361          DCA CNTR       / STORE IN COUNTER
4455   5642          JMP I ADWEG    / EXIT
4456   0310   C200,  0310           / DECIMAL 200
4457   6030   CLCONW,-1750          / MINUS DECIMAL 1000
              / SET AD FOR BONE
4460   0000   ADBON, 0              / ENTRY
4461   7201          CLA IAC        / CLEAR A AND SET TO 1
4462   7041          CIA            / COMPLEMENT TO MAKE NEG
4463   1366          TAD IB         / ADD ADDRESS
4464   3362          DCA X          / SAVE IN X
4465   1367          TAD NP         / GET ADDRESS OF NP
4466   3363          DCA NV         / SAVE IN NV
4467   1275          TAD CLCONB     / GET CLOCK CONSTANT
4470   3355          DCA CLOCK      / SET CLOCK
4471   1274          TAD C300       / GET BONE COUNTER 300
4472   3361          DCA CNTR       / STORE IN COUNTER
4473   5660          JMP I ADBON    / EXIT
4474   0454   C300,  0454           / DECIMAL 300
4475   6030   CLCONB,-1750          / MINUS DECIMAL 1000
```

FIGURE 12. RDKEY, PRINT, ADWEG AND ADBON FLOW CHARTS



ADCON - Convert AD

This subroutine is the working routine that waits to start when a microswitch closes on the densitometer, causes the analog to digital convert to convert information every second and stops when the limit microswitch on the densitometer opens.

The following is a description of the steps that occur in the subroutine. Refer to the following flow chart for the described steps.

1) The routine initializes itself by saving and setting certain locations in the memory.
2) A signal bit created by the microswitch closing on the densitometer is transferred into the computer. If the switch has closed a 1 bit is transferred into the A register.
3) A test is made to see if the 1 bit is in the A register. If 1 bit is not in the A register, the program returns to step 2. If the 1 bit is present, the program proceeds.
4) CONLP - The analog to digital converter is selected to receive information.
5) The clock count is picked up.
6) The clock count is places in location CLOC (complemented member).
7) The internal clock (IKC) is enabled.
8) The computer waits for a clock pulse.
9) The clock count CLOC is incremented by one and tested to see if it is zero. If the count is not zero, the program returns to step 7. If the count is zero, the program proceeds to the next step. Note: This loop delays a total of 1.090439 millisecond.
10) The analog to digital converter is tested to see if it is ready to transfer. If the converter is not ready to transfer, the program waits. If it is ready, the program proceeds.
11) The values read by the converter are transferred into the computer.
12) The sign bit is removed by adding 4000 octal to the number supplied by the converter.
13) The number is divided by 2 by shifting the number one binary bit to the right.

14) The number is stored in either the wedge or bone storage area which has been preset by a previous routine ADWEG or ADBON.

15) The signal bit is again transferred into the computer. If the signal bit is still present, the following steps are performed otherwise the computer proceeds to step 20.

16) The counter ICNTR (which is a complemented number) is incremented by one. If ICNTR is not zero, the program proceeds back to step 4.

17) The clock is stopped.

18) The warning 70, 70 octal is placed in the A register.

19) The computer Halts.

At this point in the program, the program has either accepted over 200 wedge points or 300 bane points before the microswitch for the end of scan has opened. This is usually a terminal condition for this bone scan. To proceed, press the continue button on the computer if the scan is on a bone. The answers that are given will be in error and can be ignored. A readjustment on the densitometer may be made and another scan performed. If this stop occurs while scanning a wedge, the same procedure can be used and the program can be caused to rescan the wedge through control numbers. Using the speed of scan and the fact that a point is taken every second, the maximum lengths of scan may be calculated. The wedge is usually 14 cm at .5cm/min. The bone lengths for 300 seconds and various speeds is given in the following table.

Speed cm/min	Scan Length cm
1	5
2	10
5	25

20) The counter in ICNTR is picked up and the number of points read into the machine calculated from this counter value.

21) The number of points is stored in a special location NV.

22) The clock is stopped.

23) Locations saved at the beginning of the routine are initialized.

24) An exit from the routine is performed.

See Figures 13 and 14 for listing and flow chart of ADCON.

FIGURE 13.

ADCON LISTING


```
                  / CONVERT AD
                         / DEFINE CLOCK CONTROL INSTRUCTIONS
                         SCLF=6371
                         ENCL=6374
                         STCL=6372
4476   0000   ADCON,  0                   / ENTRY
4477   7300           CLA CLL             / CLEAR AL
4500   1011           TAD 11              / GET LOCATION 11
4501   3353           DCA S11             / SAVE LOCATION 11
4502   1362           TAD X               / GET LOCATION IN X
4503   3011           DCA 11              / SET LOCATION 11
4504   1361           TAD CNTR            / GET COUNTER
4505   7041           CIA                 / COMPLEMENT
4506   3360           DCA ICNTR           / SET IN ICNTR
4507   7604           LAS                 / TRANSFER SIGNAL BIT
4510   7500           SMA                 / SKIP ON MINUS (CLOSED CIRCUIT)
4511   5307           JMP .-2             / WAIT FOR SIGNAL
4512   6532   CONLP,  ADCV                / SELECT CONVERT AD      6532
4513   7300           CLA CLL             / CLEAR A L
4514   1355           TAD CLOCK           / GET CLOCK
4515   3356           DCA CLOK            / SET CLOCK ADDRESS
4516   6374   CLK,    ENCL                / ENABLE CLOCK
4517   6371           SCLF                / SKIP ON CLOCK FLAG SET
4520   5317           JMP .-1             / WAIT FOR CLOCK FLAG
4521   2356           ISZ CLOK            / INCREMENT AND SKIP IF ZERO
4522   5316           JMP CLK             / GO WAIT CLOCK INCREMENT
4523   6531           ADSF                / SKIP ON AD FLAG SET    6531
4524   5323           JMP .-1             / JUMP BACK TO WAIT
4525   6534           ADRB                / READ AD CONVERTER BUFFER
4526   1354           TAD 04              / ADD 4000 OCTAL
4527   7110           CLL RAR             / CLEAR LINK AND ROTATE RIGHT 1 (DIVIDE
4530   3411           DCA I 11            / STORE INDIRECTLY (INDEXED VALUE IN 11)
4531   7604           LAS                 / TEST SWITCH CLOSED
4532   7500           SMA                 / NEG IF SWITCH CLOSED
4533   5342           JMP CONCOM          / CONVERSION COMPLETE (SWITCH OPEN)
4534   2360           ISZ ICNTR           / INCREMENT COUNTER AND SKIP IF ZERO
4535   5312           JMP CONLP           / CONVERT AD
4536   7300           CLA CLL             / CLEAR A L
4537   6372           STCL                / STOP CLOCK
4540   1357           TAD WA              / GET WARNING 7070
4541   7402           HLT                 / HALT
4542   7300   CONCOM, CLA CLL             / CLEAR A L
4543   1360           TAD ICNTR           / GET COUNTER REMAINING AND SUBTRACT
4544   7001           IAC                 / INCREMENT COUNTER FOR LAST POINT
4545   1361           TAD CNTR            / FROM BASE VALUE CNTR
4546   3763           DCA I NV            / SAVE IN NUMBER OF VALUES
4547   6372           STCL                / STOP THE CLOCK
4550   1353           TAD S11             / GET SAVED LOCATION 11
4551   3011           DCA 11              / STORE IN LOCATION 11
4552   5676           JMP I ADCON         / EXIT
4553   0000   S11,    0                   / SAVE 11
4554   4000   04,     4000                / 4000 OCTAL CONSTANT
4555   0000   CLOCK,  0                   / CLOCK SET VALUE (COMPLEMENT)
4556   0000   CLOK,   0                   / WORKING COMPLEMENT
4557   7070   WA,     7070                / WARNING 7070
4560   0000   ICNTR,  0                   / COMPLEMENTED COUNTER FOR SCAN LENGTH
4561   0000   CNTR,   0                   / C[illegible]R FOR SC[illegible] LENGTH
4562   0000   X,      0                   / [illegible] OF A[illegible]A STOR[illegible]
4563   0000   NV,     0                   / [illegible] OF [illegible]
```

FIGURE 13.

ADCON LISTING


```
                    / **** THE FOLLOWING ADDRESSES MAY HAVE TO BE CHANGED ****
4564   7325   IW,      7325    / WEDGE ADDRESS
4565   6457   NW,      6457    / NUMBER OF WEDGE POINTS ADDRESS
4566   6651   IB,      6651    / BONE ADDRESS
4567   6461   NP,      6461    / NUMBER OF BONE POINTS

                    RDKEY    4426
                    RPT      4416
                    SC       4346
                    SCLF     6371
                    SETAD    4322
                    SETBO    4330
                    SPB      4415
                    SPCR     4362
                    SPCY     4304
                    STCL     6372
                    S10      4345
                    S11      4553
                    TRE      4351
                    WA       4557
                    WAITCR   4400
                    WAITSP   4407
                    WATC     4340
                    WATS     4341
                    WFTB     4314
                    X        4562
                    XXX      4425
```

FIGURE 14.

ADCON FLOW CHART

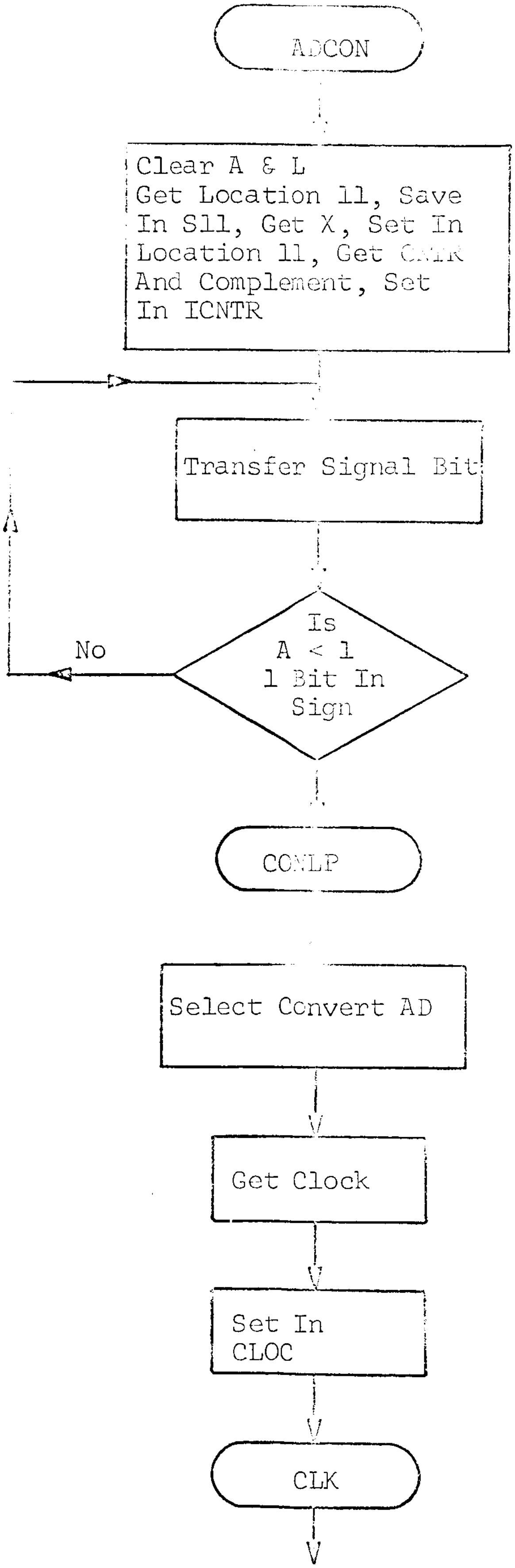


FIGURE 14.

ADCON FLOW CHART

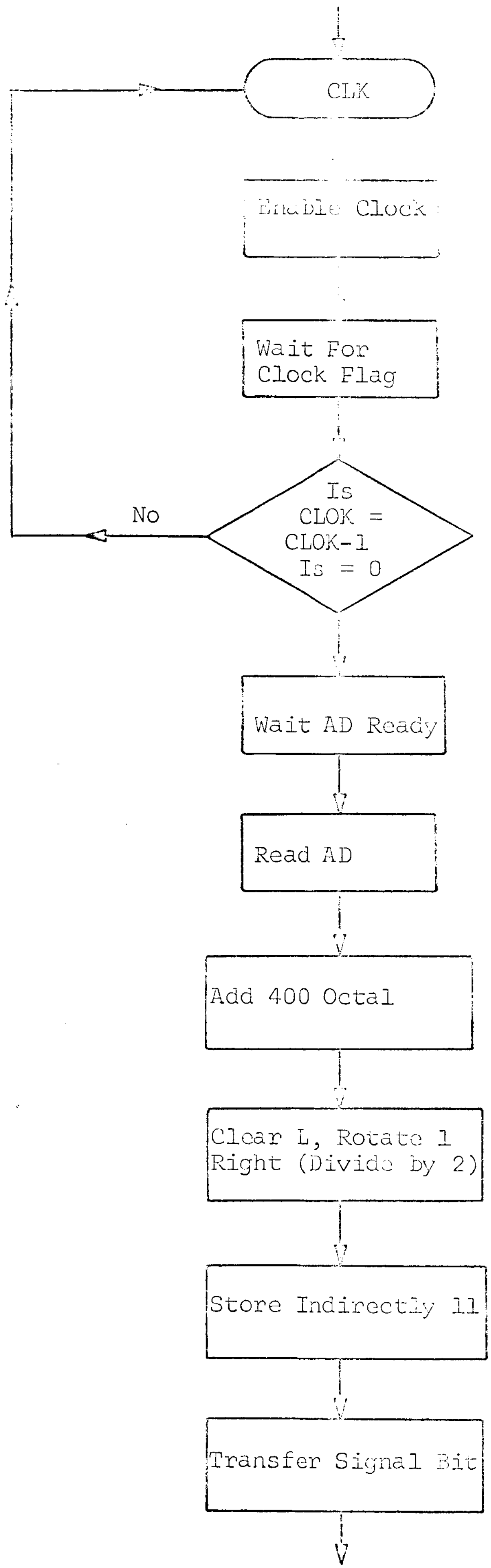
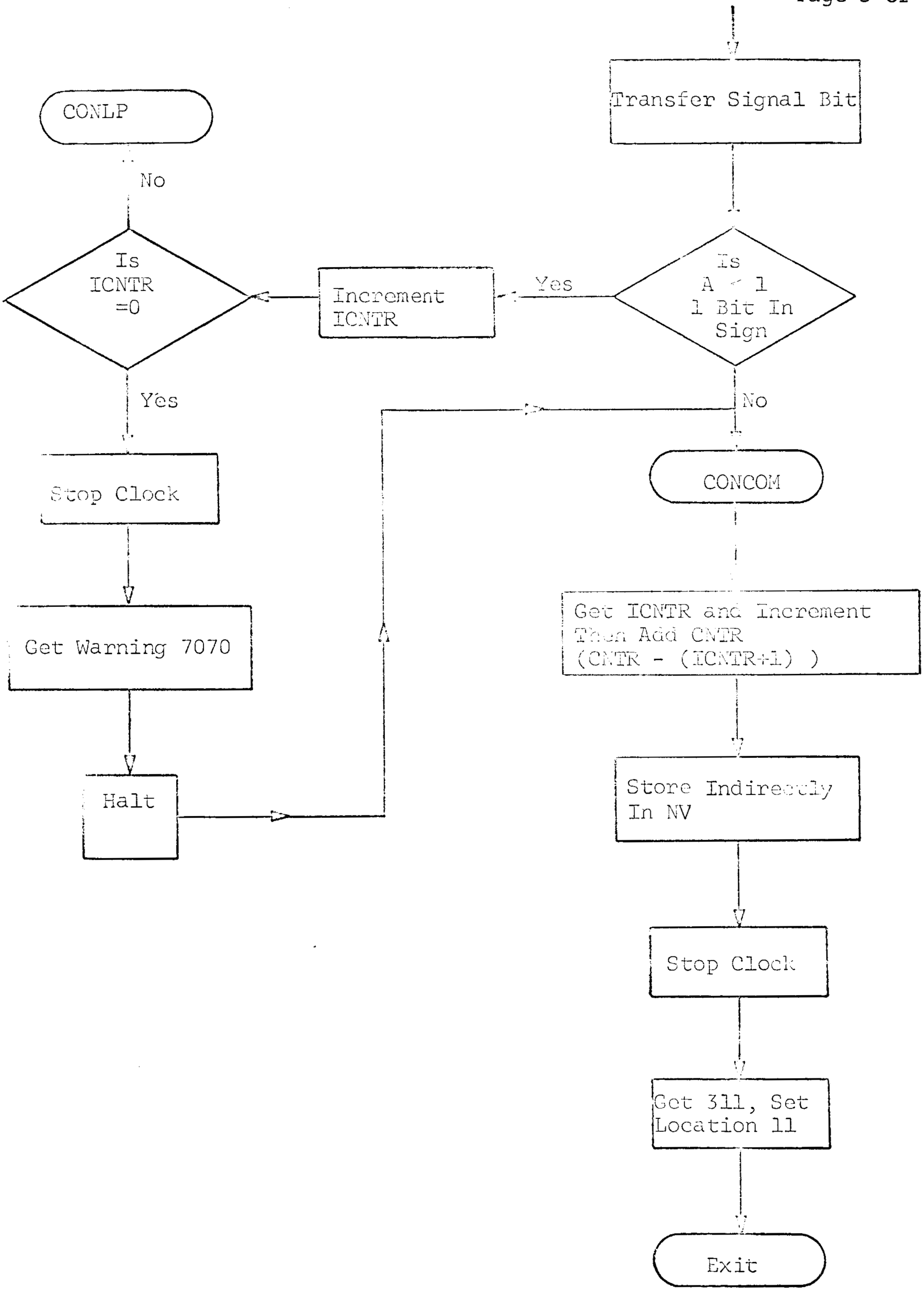


FIGURE 14.

ADCON FLOW CHART



RDYSP - Read Special Tape

The following routine is a special purpose program that was used in the creation of the final working program. Once this routine had done its initial job, it was destroyed by the working program. However, this program could be read into the machine and used to create new heading and control information. Caution: Other parts of the program could be affected because they refer to addresses within the character string.

This routine is used to read in a special tape consisting of a string of control characters and heading data, packs this information into a condensed character form and stores this information is serial sequence in the memory.

The following is the character string tape that was processed by this program. Refer to subroutine INPRN for the manner in which the characters are interpreted.

/SUBJECT NAME:SUBJECT NUMBER:EXPERIMENTAL UNIT:DATE OF RADIOGRAPH: DIET://DATE OF SCANNING: OPERATOR OF XRAY MACHINE:OPERATOR OF DENSITOMETER:///BONE:BONE SITE:TYPE OF WEDGE:TYPE OF SCAN:UNITS OF OUTPUT:////;WEDGE!*$;/BONE!*/////$

See Figures 15 and 16 for RDYSP listing and flow chart.

FIGURE 15.

RDYSP LISTING

```
                *7000
                / READ IN SPECIAL TAPE
7000    7300    RDYSP,  CLA CLL         / CLEAR A L
7001    1010            TAD 10
7002    3257            DCA SL10
7003    1260            TAD ICHAR
7004    3010            DCA 10
7005    4653    RDLO,   JMS I READT
7006    7450            SNA
7007    5205            JMP RDLO
7010    5212            JMP RDLO2
7011    4653    RDLO1,  JMS I READT
7012    0254    RDLO2,  AND ML77
7013    7100            CLL
7014    3256            DCA XX
7015    1256            TAD XX
7016    7006            RTL
7017    7006            RTL
7020    7006            RTL
7021    3255            DCA UHC
7022    1256            TAD XX
7023    1261            TAD M44
7024    7450            SNA
7025    5242            JMP ENDR
7026    7300            CLA CLL
7027    4653            JMS I READT
7030    0254            AND ML77
7031    3256            DCA XX
7032    1256            TAD XX
7033    1255            TAD UHC
7034    3410            DCA I 10
7035    1256            TAD XX
7036    1261            TAD M44
7037    7440            SZA
7040    5211            JMP RDLO1
7041    5244            JMP EXITR
7042    1255    ENDR,   TAD UHC
7043    3410            DCA I 10
7044    1010    EXITR,  TAD 10
7045    3256            DCA XX
7046    1257            TAD SL10
7047    3010            DCA 10
7050    1256            TAD XX
7051    7402            HLT
7052    5252            JMP .
7053    4426    READT,  4426    / READ TELE **** THIS MAY HAVE TO BE CHANGED
7054    0077    ML77,   0077            / MASK
7055    0000    UHC,    0               / UPPER HALF CHARACTER
7056    0000    XX,     0               / LOWER SAVE
7057    0000    SL10,   0               / SAVE 10
7060    6324    ICHAR,  6324    / CHARACTER STORAGE **** THIS MAY HAVE TO BE C
7061    7734    M44,    -0044           / MINUS 44 OCTAL
```

FIGURE 15.

RDYSP LISTING


```
ENDR    7042
EXITR   7044
ICHAR   7060
ML77    7054
M44     7061
RDLO    7005
RDLO1   7011
RDLO2   7012
RDYSP   7000
READT   7053
SL10    7057
UHC     7055
XX      7056
```

FIGURE 16.

RDYSP FLOW CHART

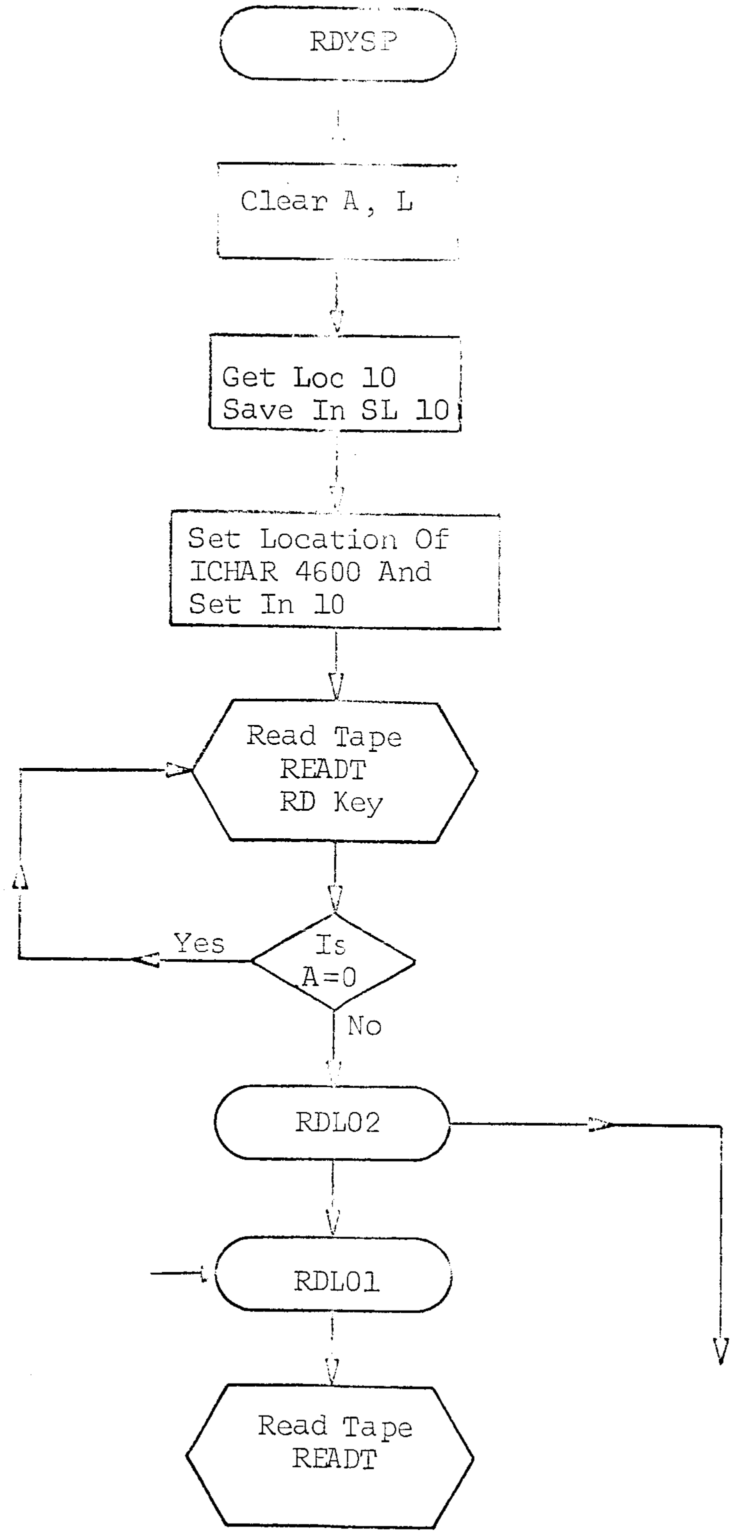


FIGURE 16.
RDYSP FLOW CHART

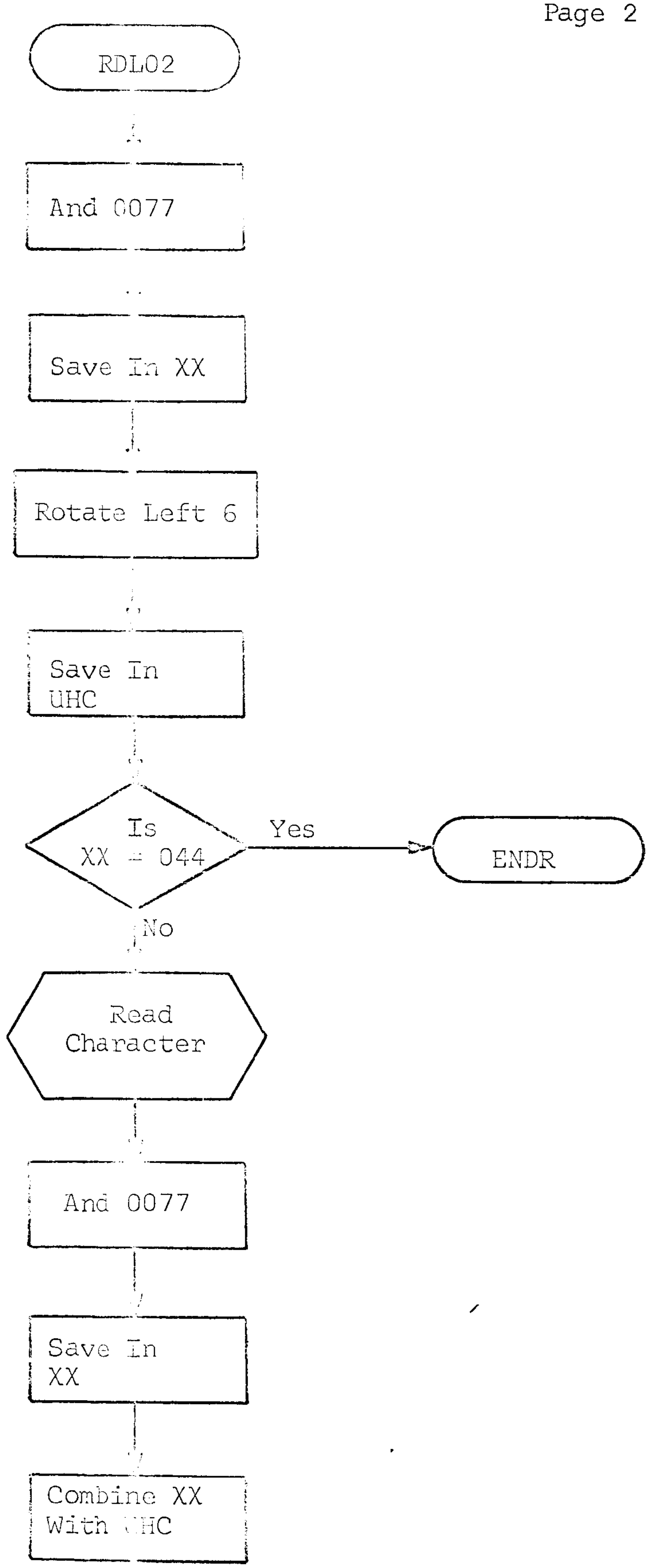
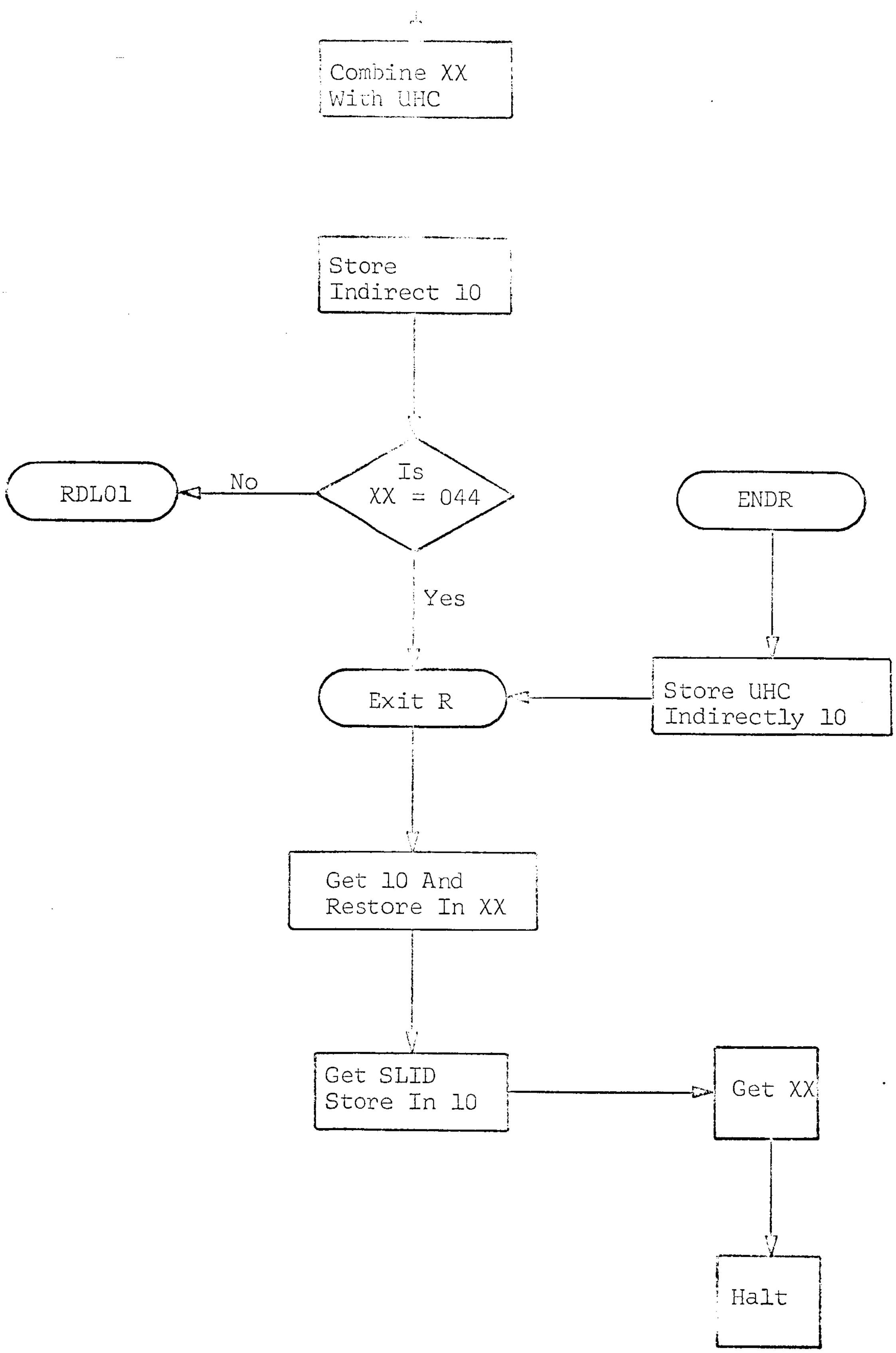


FIGURE 16.

RDYSP FLOW CHART



C. Program Loading, Operation and Output

The general information in the Digital Equipment Corporation Manual F-81 (PDP-8, A High Speed Digital Computer), Manual F-85 (PDP-8 Users Handbook), and Manual DIGITAL 8-2-S (PDP-8 Fortran Programming Manual) is assumed to be available and the user is assumed to be familiar with the information in these manuals. These manuals contain detailed descriptions of operating instructions for the computer.

Appendix 6, page 242, of Manual F-85 and Appendix C, page 47 of Manual 8-2-S give the RIM loader, the sequence to use the RIM loader to load a BINARY LOADER, and information to use the BINARY LOADER to load a binary program tape. The sequence of usage is as follows.

1) The RIM loader is manually loaded through the console into locations 7756 through 7777. This loader is as follows:

ADDRESS	CONTENTS
7756	6032
7757	6031
7760	5357
7761	6036
7762	7106
7763	7006
7764	7510
7765	5357
7766	7006
7767	6031
7770	5367
7771	6034
7772	7420
7773	3776
7774	3376
7775	5356
7776	0000
7777	0000

2) After the RIM loader is in the machine the BINARY LOADER may be loaded from paper tape. The BINARY LOADER is a short program on paper tape that is in the PDP-8 tape library and is identified on the tape label. This tape is loaded by using the instructions in Appendix 6 of Manual F-85 or Appendix C of Manual 8-2-S for the use of the RIM loader.

3) The bone density program is on a binary tape that may be loaded by the binary loader. When the binary loader is in the machine, the instructions for using the binary loader are in Appendix 6 of Manual F-85 or Appendix C of Manual 8-2-S. Note: The binary loader may be restarted at 7756 in addition to 7777.

4) Once the program is loaded, it may be started at location 0201. All console switches should be in normal operating positions. <u>The switch register switch corresponding to bit 0 must always be down</u>. The control switching from the optical scanner limit switches is brought to the computer through this position of the switch register.

The program at various stages prints out the word WAITING. The program is waiting for two single digit control numbers to be typed into the computer. These two numbers are designated KS and IPS and are entered in that sequence. The following table indicates the options specified by these control numbers.

KS*	IPS*	FUNCTION	SPEED	OUTPUT
9	9	Scan wedge and print	5.0 cm/min only	NA
9	0	Scan wedge, no heading	5.0 cm/min only	NA
-9	0	Scan bone	Accept speed entry	Total only
0	-9	Scan bone	Accept speed entry	1/10 increments and total
0	0	Scan bone	Use previous speed	Total only
0	9	Scan bone	Use previous speed	1/10 increments and total

First WAITING always: 9,9 or 9,0

Second WAITING always: -9,0 or 0,-9

*Note: The value of the numerical digit other than zero is immaterial. The number may be any single digit because the program determines only if it is less than, equal to, or greater than zero.

Step-by-step operating procedures are given in Section II of this report.

Samples of output from this program are found in Figure 17. Reference can be made to these while reading the following descriptions.

There are several options on output for this program. On the wedge scan identifying information may be typed in following headings that are printed out or the wedge can be scanned without the headings. Example 1 on the output shows control numbers 9,0, then WEDGE, then WAITING. This is the sequence for no heading information. Example 2 shows the 9,9 entry which causes the wedge to be scanned and headings to be printed. Following the colon on each entry any character may be typed up to a carriage return which terminates the line. The computer proceeds to print the next line of identifying information and/or skip line spaces. When the heading is finished the computer causes the typewriter to space up several lines and types WEDGE indicating that the computer is ready to scan the wedge. When the wedge has been scanned, the computer goes back to a waiting status ready to receive the next control numbers.

The bone scan phase has one input and several output options. In example 3, the entry -9,0 is used calling for a speed change and no print out of one-tenth segments of the total integrated section. The output is as shown. The typewriter first types SCAN SPEED then pauses for the operator to make an entry to indicate the scan speed. The computer accepts the scan speed, then types BONE to indicate that the machine is waiting for the bone. When the bone is scanned, the printout gives the number of sample points and the length scanned. This output is obtained on all bone scans. Then the total integrated area is printed, followed by a scaled number to correspond to a wedge equivalent value.

Example 4 illustrates the output when the printing of the ten segments of the total area is desired.

Examples 5 and 6 show typical printouts of bone scan data for which a new scan speed was not entered.

FIGURE 17.

PROGRAM OUTPUT EXAMPLES

```
                    WAITING

9,0
WEDGE
```

FIGURE 17.

PROGRAM OUTPUT EXAMPLES

```
WAITING

  9,9
SUBJECT NAME:
SUBJECT NUMBER:
EXPERIMENTAL UNIT:
DATE OF RADIOGRAPH:
DIET:


DATE OF SCANNING:
OPERATOR OF XRAY MACHINE:
OPERATOR OF DENSITOMETER:



BONE:
BONE SITE:
TYPE OF WEDGE:
TYPE OF SCAN:
UNITS OF OUTPUT:



WEDGE
```

FIGURE 17.

PROGRAM OUTPUT EXAMPLES

```
WAITING

  -9,Ø

SCAN SPEED5.Ø

BONE



NUMBER OF SAMPLE POINTS: +156
BONE LENGTH (CM): +Ø.13ØØØØE+2

     TØTAL:        +Ø.627792E+4      +Ø.3Ø7618E+1
```

FIGURE 17.

PROGRAM OUTPUT EXAMPLES

```
WAITING

  Ø,-1

SCAN SPEED 5.Ø

BONE



NUMBER OF SAMPLE POINTS: +156
BONE LENGTH (CM): +Ø.13ØØØØE+2

     SEGMENT        INTEGRATED COUNTS

      +1               +Ø.564274E+2
      +2               +Ø.2ØØ355E+3
      +3               +Ø.332119E+3
      +4               +Ø.467211E+3
      +5               +Ø.598286E+3
      +6               +Ø.731374E+3
      +7               +Ø.8Ø5Ø87E+3
      +8               +Ø.921Ø55E+3
      +9               +Ø.1Ø3Ø56E+4
      +1Ø              +Ø.114843E+4

      TØTAL:         +Ø.629Ø86E+4        +Ø.3Ø8252E+1
```

FIGURE 17.

PROGRAM OUTPUT EXAMPLES

```
WAITING

  0

DONE




NUMBER OF SAMPLE POINTS: +156
BONE LENGTH (CM): +0.130000E+2

     SEGMENT      INTEGRATED COUNTS

      +1             +0.537312E+2
      +2             +0.200879E+3
      +3             +0.333556E+3
      +4             +0.466897E+3
      +5             +0.599473E+3
      +6             +0.733128E+3
      +7             +0.804256E+3
      +8             +0.919658E+3
      +9             +0.103336E+4
      +10            +0.115105E+4

      TOTAL:       +0.629595E+4        +0.308501E+1
```

FIGURE 17.
PROGRAM OUTPUT EXAMPLES


```
WAITING

  0,0

BONE



NUMBER OF SAMPLE POINTS: +156
BONE LENGTH (CM): +0.130000E+2

      TOTAL:        +0.636448E+4        +0.3[illegible]19E+1
```

D. Interface - Computer to Densitometer System

The Computer System interface with the existing densitometer system consists of two signal lines: (1) the analog voltage signal that is functional with the optical density of the film, and (2) a switched 115vac signal that indicates the scan limits (this voltage is the chart drive signal to the Speedomax G recorder connected to the densitometer output). These two input signals along with the operator inputs to the Teletype Input/Output unit provide complete interface with the original system.

The details of the connections appear in Section V of this document.

IV. SYSTEM MAINTENANCE

The digital system components supplied on this contract were chosen to provide long-life trouble-free operation under the anticipated operating conditions. However, a system of this complexity should be checked in accordance with some periodic maintenance program to assure operation meeting original specifications.

The system user should formulate a maintenance program compatible with his needs and operating schedules. The following outline provides a basis for a comprehensive system maintenance program:

1) Specific system components should be maintained as outlined in manufacturers instruction manuals.

2) The computer program should be loaded into the computer at least once a week.

3) The digital computer should be checked periodically (every one to three months) by means of the diagnostic tapes supplied by the computer manufacturers. Any computer malfunctions should be corrected by a factory representative.

4) Teletype machines are limited-life devices and require maintenance from time to time. This machine should be operated no more than necessary (when the system is ON but idle for long periods of time, the switch on the front of the teletype machine should be switched to the OFF position). Service and maintenance on this unit should be performed by the computer representative or by a qualified teletype serviceman.

A maintenance program encompassing the foregoing points should assure optimum system operation. Factory representative service on the computer system (including the teletype machine) can be obtained either on an "ON-CALL" or on a "MAINTENANCE CONTRACT" basis. A primary advantage of contract maintenance is that the periodic diagnostic checks are included as part of such a contract.

V. CIRCUIT DOCUMENTATION

A block diagram of the bone density instrumentation in use at TWU is shown in Figure 18. The dashed blocks indicate the existing analog instrumentation and the solid blocks indicate the digital instrumentation supplied on this contract. The Knorr-Albers Scanning Microphotometer contains a mechanical assembly, optical system, photocell and preamplifier, and limit switches to provide the following signals:

1) An analog voltage functional with the optical density (transmittance) of the film being scanned;
2) A signal line that provides 115VAC during the scan period.

In the existing instrumentation, a Leeds & Northrup Speedomax G Servo Recorder is used to follow the preamplifier output voltage and the 115VAC signal is used to advance the chart paper through the recorder.

The digital computer system is programmed to duplicate the computations of the analog system and requires the same two sets of information: (1) the analog voltage functional with film density, and (2) the signal indicating the scan limits. Since the basic range of the microdensitometer preamplifier output voltage is about 5 millivolts, an amplifier to amplify this signal to the 10 volt level required by the Analog-to-Digital (A/D) Converter in the digital computer. An isolated ground amplifier (Astrodata Model 885) is used to isolate the system grounds, and the 115VAC scan signal is isolated by means of a relay.

The system interconnections are shown in Figure 19. The circuit details of the microphotometer recorder can be found in Leeds & Northrup Drawing SSS-672-A-10 and the circuit details of the microphotometer can be found in Leeds & Northrup Drawing D-2145 (these drawings are part of the documentation on the existing analog system). As a matter of convenience, connections were made at the terminal strip in the microphotometer Speedomax G Recorder.

The Astrodata amplifier and isolating relay are mounted in a chassis assembly located in the top of the computer rack. The circuit diagram

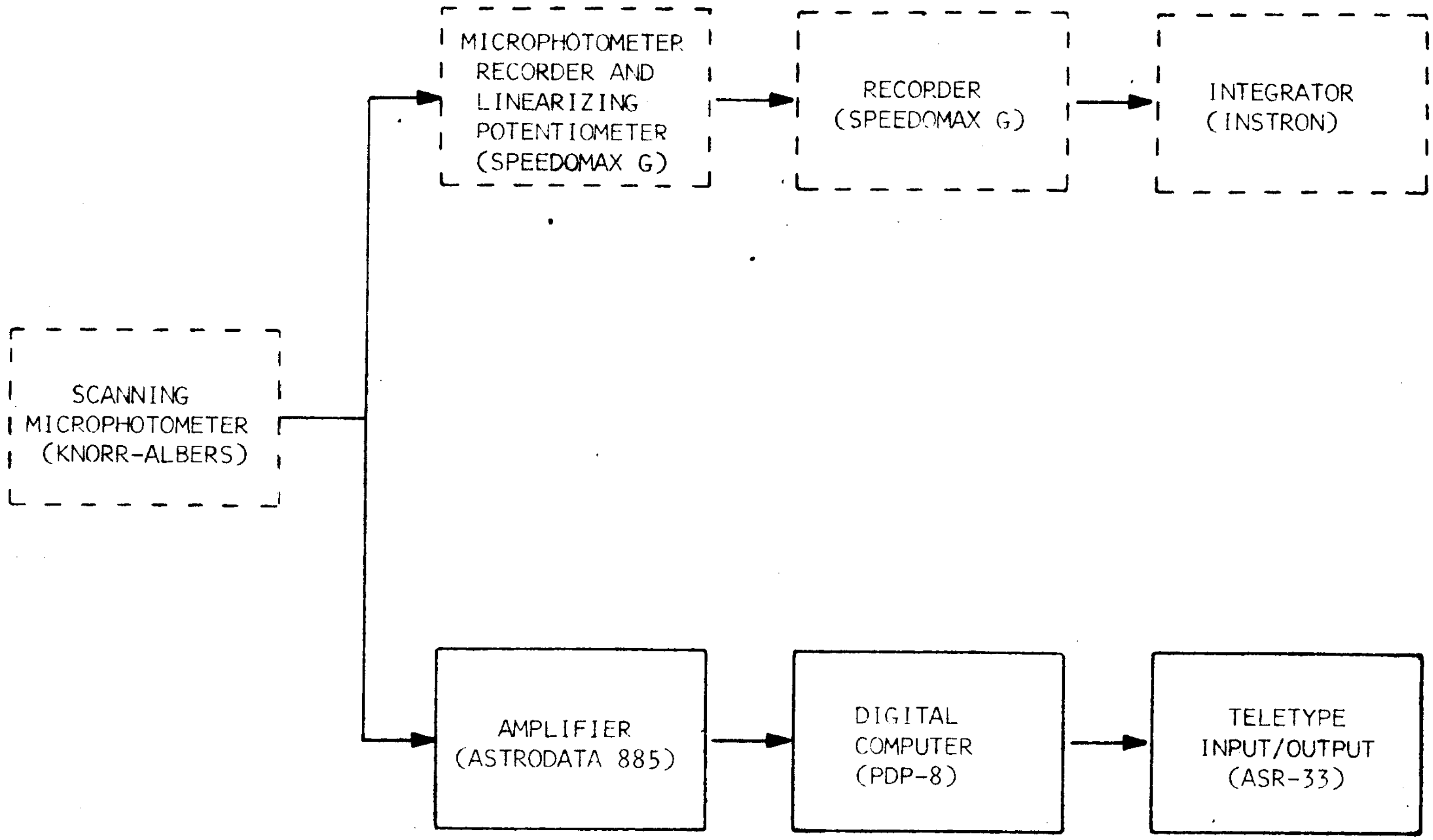


FIGURE 18. BLOCK DIAGRAM OF BONE DENSITOMETRY INSTRUMENTATION

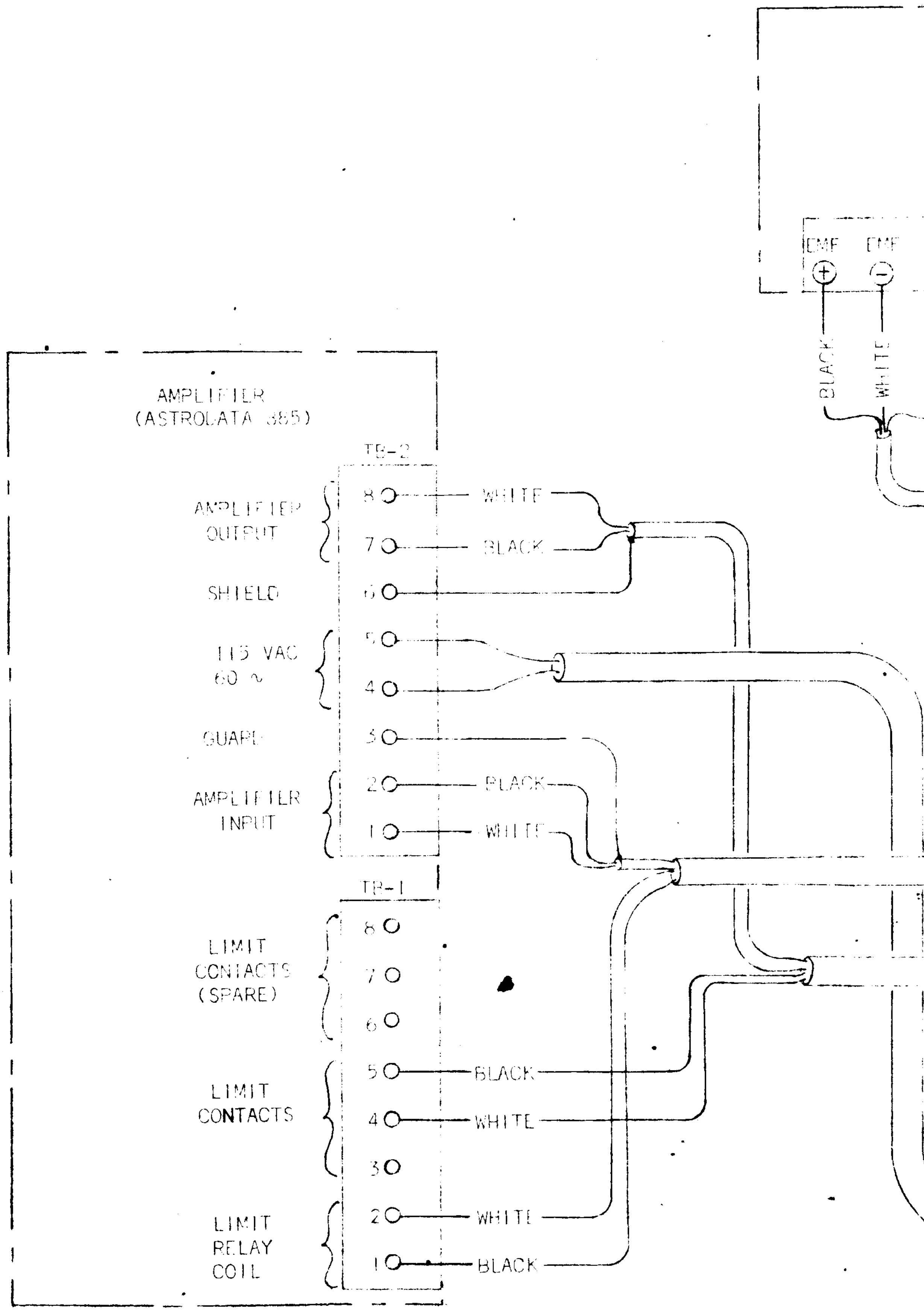
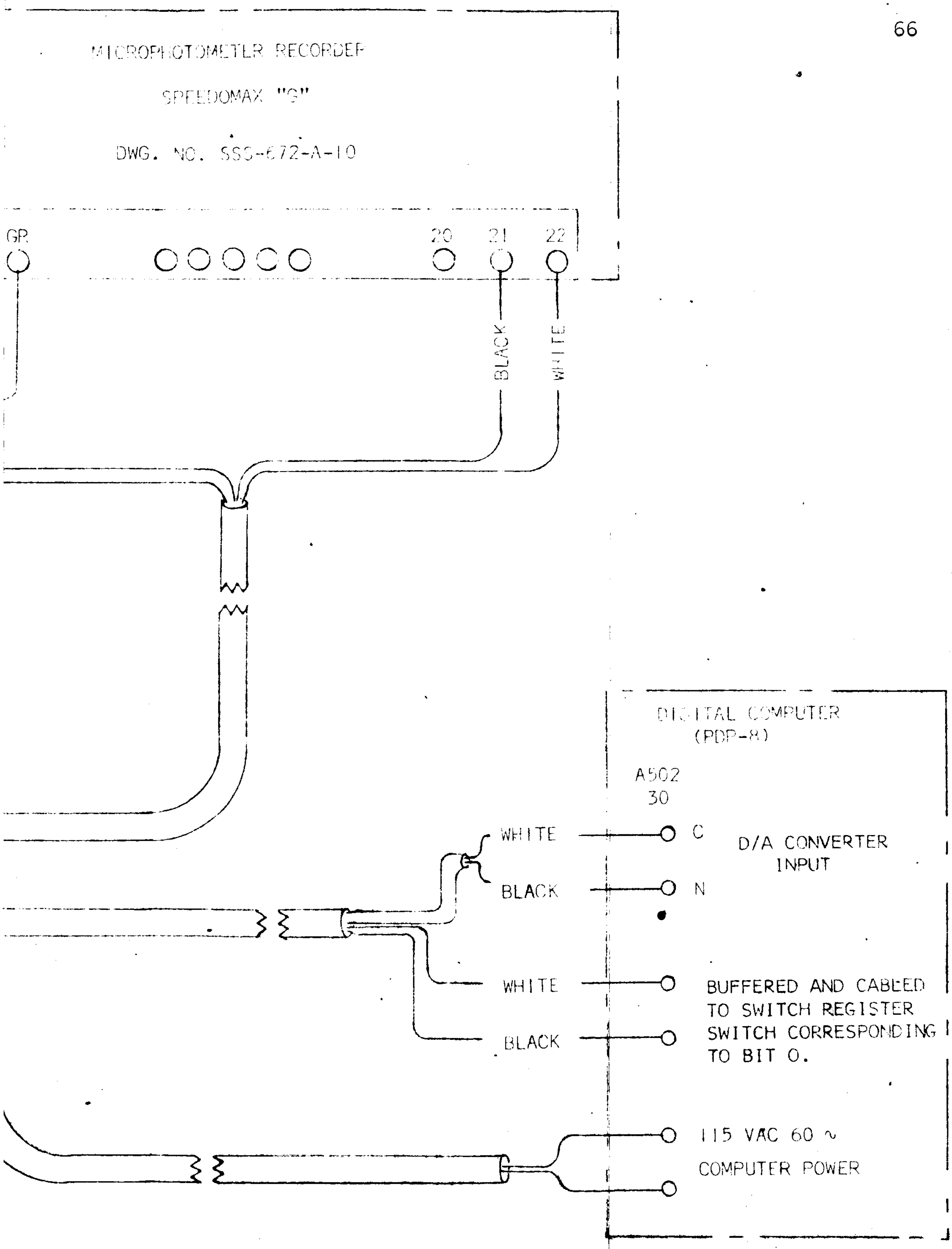


FIGURE 19. BONE DENSITY CON



IPUTER INTERCONNECTION DIAGRAM

of this assembly is shown in Figure 20. A meter connected to the output of the amplifier provides the operator with a means to set and/or check the input voltage to the A/D Converter (0 to -10 volts).

The analog voltage from the Astrodata amplifier is connected to the input terminals of the A/D Converter in the digital computer. The scan limit relay provides a contact closure to the computer indicating the scan period. These connections are made at spare terminals in the A/D Converter, and are connected through a spare cable in the computer to the Switch Register (BIT 1). (These connections are documented on the computer drawings.) The program utilizes this bit in the program to sense scan limits (see Section III). Teletype connections are not shown in Figure 19 because this unit is included as part of the computer. Note that the power switch on the computer activates all components in the digital system.

Tests with the digital system indicated that the microdensitometer preamplifier drift was excessive and did not permit good repeatability. The vacuum tube preamplifier was replaced with a transistorized unit exhibiting far superior drift characteristics. The diagram of this unit is shown in Figure 21 and replaces the "Lamp Control and Amplifier Panel" shown in Leeds & Northrup Drawing D-2145. Operating controls and characteristics were maintained as in the original preamplifier unit.

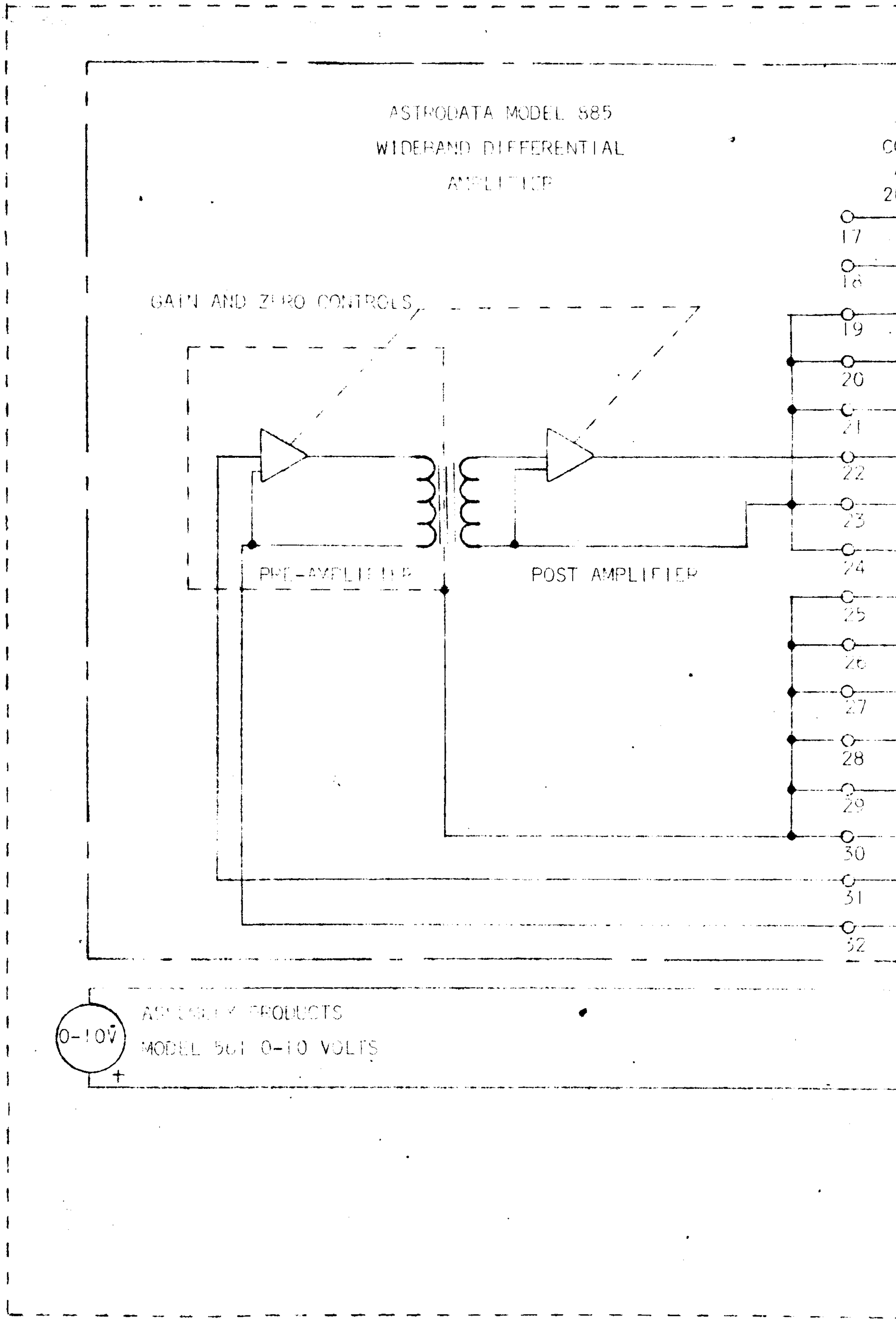
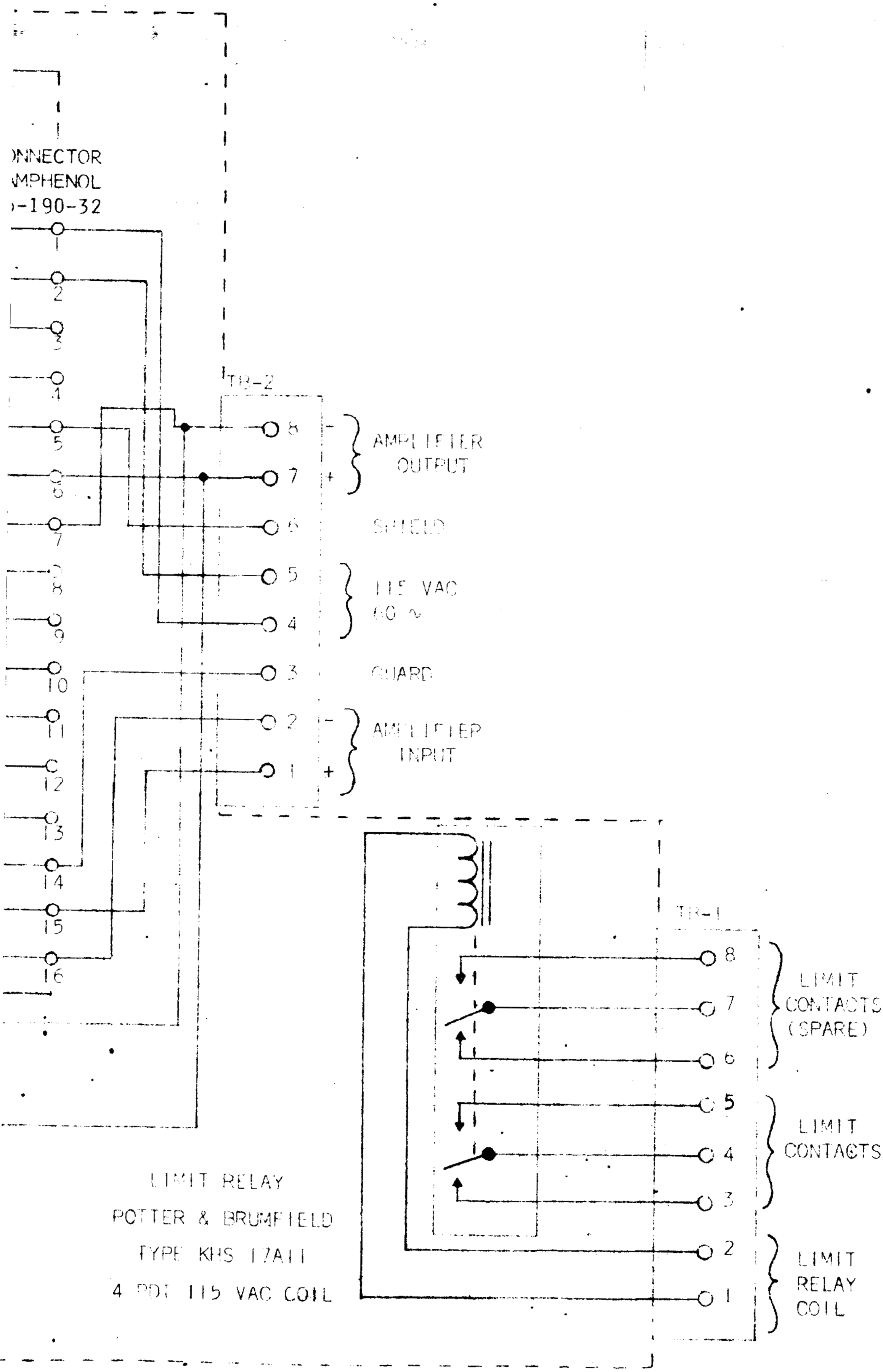


FIGURE 20. BONE DENS



ITY COMPUTER AMPLIFIER

2

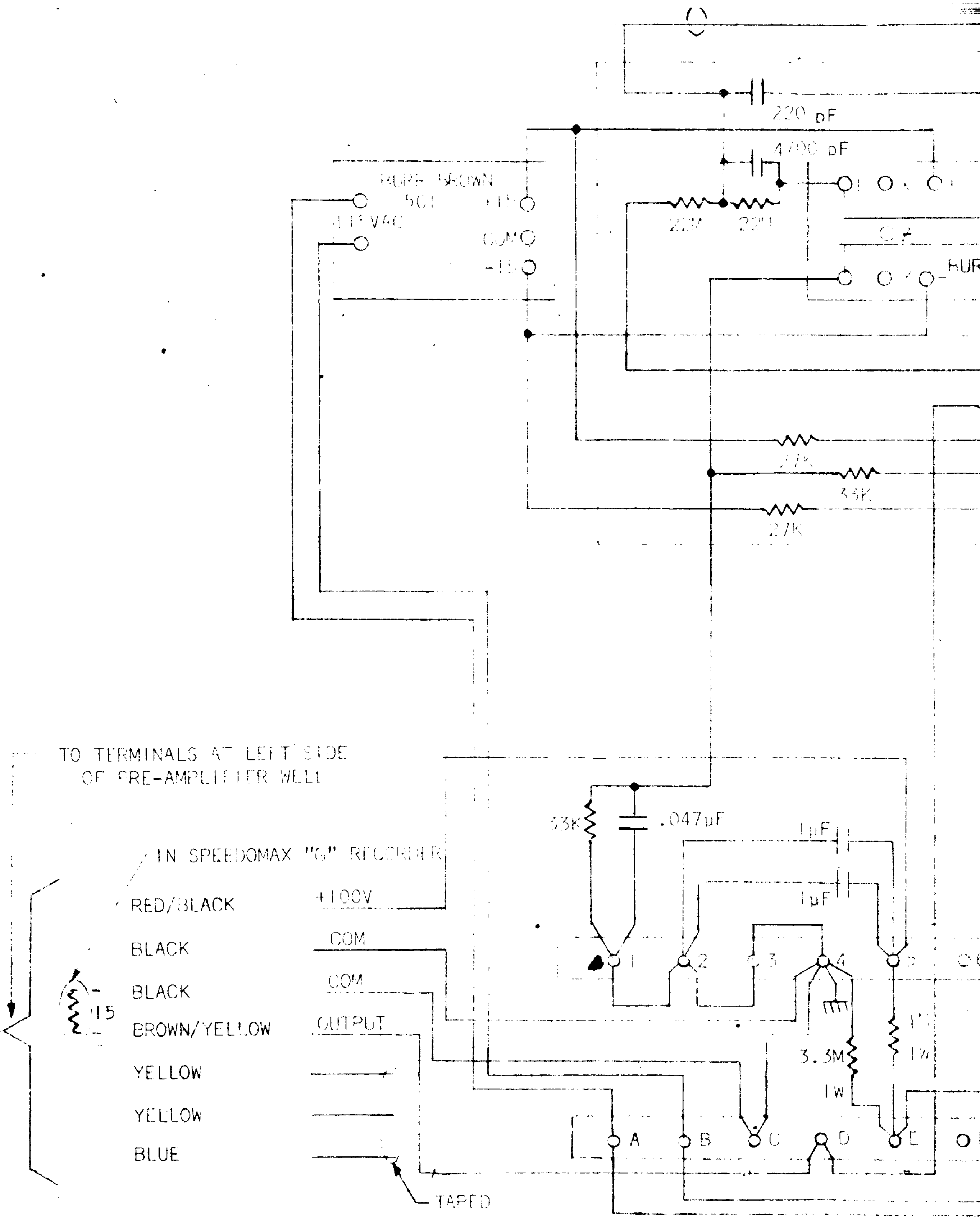
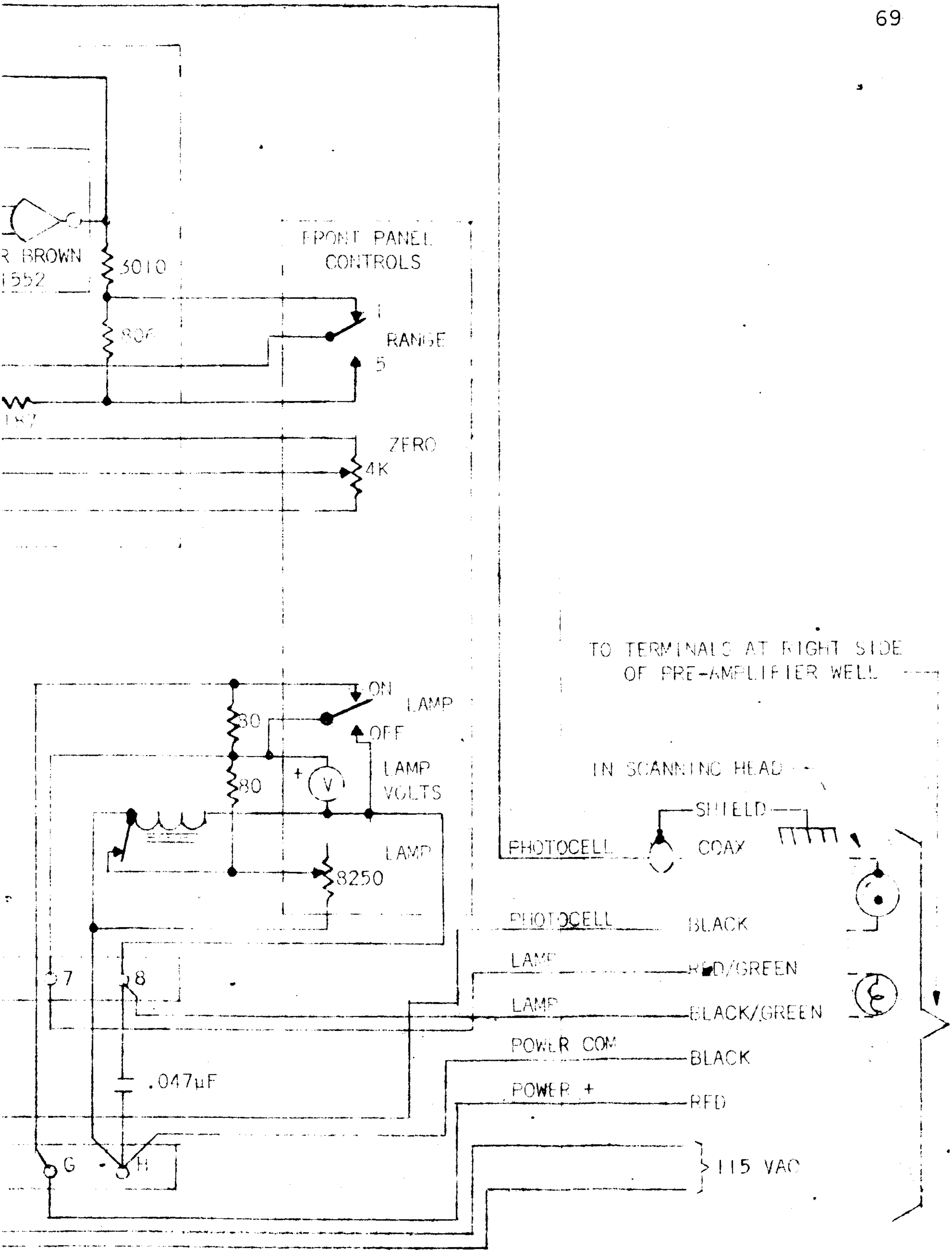


FIGURE 21. KAMAN INSTRUMENTS MIC



OPHOTOMETER PREAMPLIFIER